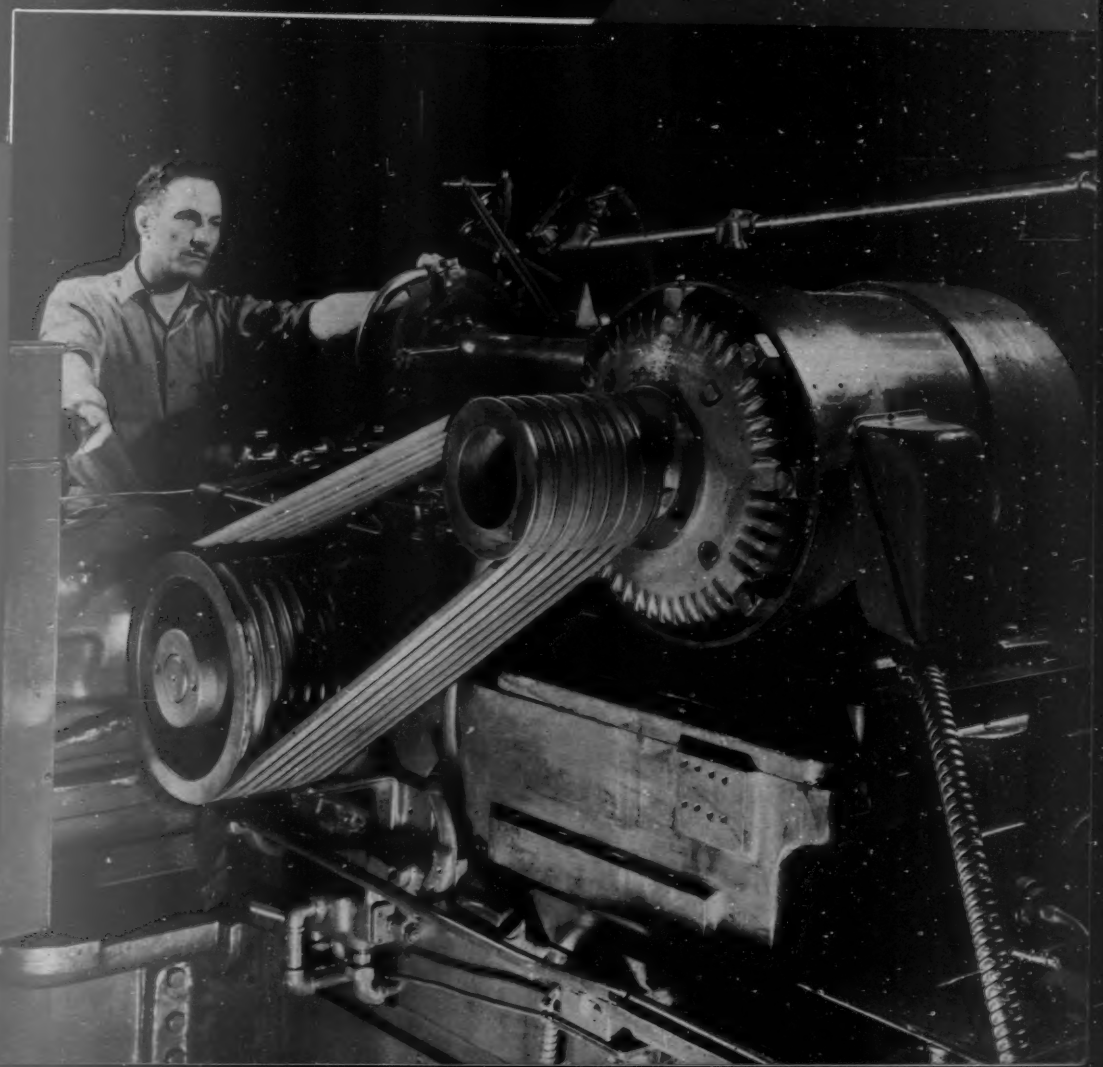
ALLIS-CHALMERS

ELECTRICAL REVIEW

June • 1941



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These 5/8% Step Regulators Are Famous for Better Regulation at Lower Cost!

DFR — 12 to 250 kva, single phase
AFR — 20.8 to 750 kva, three phase
CFR (air cooled) — 36-96 kva, 2400 volt, single phase

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ELECTRICAL REVIEW

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MAKE AND BREAK

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CIRCUIT BREAKER SALES • ALLIS-CHALMERS MANUFACTURING COMPANY

Second only to the importance of interrupting speed and reliability in a circuit breaker are its reclosing characteristics. On test, the pneumatically-operated breakers for Santee-Cooper's Pinopolis power house showed unusual advantages on both counts.

In 1771 Henry Mouzon Jr., was employed by the Province of South Carolina to plan an inland navigation canal between the Santee and Cooper Rivers. The project, completed in 1800 at a cost of $750,000, provided a ship channel 22 miles long and 35 ft wide, but with a minimum depth of only four feet. Ten locks of brick and stone lifted and lowered barges.

Today most of the old canal is flooded by water in the two reservoirs, the Santee and the Pinopolis. The eight miles of diversion canal that connect the two man-made lakes will be 200 ft wide and a minimum of 10 ft deep at low water. A single navigation lock with a chamber 180 ft long and 60 ft wide will lift boats 75 ft from the Cooper River to the interconnected lakes. At the end of the Pinopolis reservoir beside the navigation lock is the 380 ft long power house in which four 34,000 kva turbines and generators will convert the hydraulic energy into power. The project will be completed this year at a cost of $40,795,000, and its ultimate hydro capacity will be 163,000 kw. Fig. 1 is an artist's conception of the project.

The 40 mile long Santee reservoir, created by water backed up from the main dam, will cover 155 square miles. The Pinopolis reservoir, filled with water diverted from the Santee reservoir, will have a maximum depth of 65 ft and will cover 95 square miles of land. Starting from the power house at the foot of the Pinopolis reservoir is the four and one-half mile tail race carrying spent water to the Cooper River.

Earth construction is used on the two dams, except on the spillway, navigation lock, and power house. The Santee dam, near Wilson Landing, is nearly eight miles long and has a 3400 ft concrete spillway. The Pinopolis dam is two miles long, but about 26 miles of earth dykes have been built to create the Pinopolis reservoir.

AT LEFT: On the test floor — a 65,000 kva hydrogen-cooled turbo-generator.

Power from the Santee-Cooper project will be utilized by South Carolina industries, and abundant low-cost power is also expected to bring in new industries. The South Carolina Public Service Authority is working with other organizations in an effort to find expanding markets for this power. One of the largest hydroelectric projects in the South, the Santee-Cooper development has been designated "a necessity to National Defense" by OPM Director Wm. S. Knudsen.

Circuit breaker considerations

Transformers at the Pinopolis power house will raise the generated voltage from 13,800 volts to 115 kv for distribution through six ultra-high-speed reclosing outdoor oil circuit breakers. The breakers, four of which are shown in Fig. 2, are each rated 600 amp, 115 kv, 1,500,000 kva interrupting capacity.

The area to be served by the Pinopolis power plant is subject to severe electrical storms and high winds, and it has been found that about 90 percent of the transmission line faults are initiated by lightning surges and are non-permanent in nature. Transient voltages cause a flashover to ground creating a short circuit through which heavy fault current flows. If, however, the power arc can be interrupted long enough for the air to deionize, the line voltage alone will be unable to re-establish flashover. By means of rapidly reclosing circuit breakers, it is hoped to eliminate outages from these causes and thus minimize duplication of transmission lines.

Studies have shown that a dead time of 7 to 12 cycles is necessary to deionize the path of a power arc. Also, the system disturbance becomes less as the actual dead time approaches the minimum dead time.

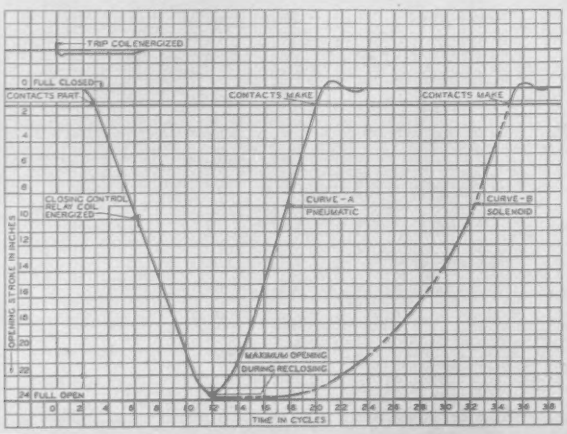
Limitations of solenoid operators

The standard reclosing time designated by the National Electrical Manufacturers' Association for 115 kv outdoor "ultra-high-speed" reclosing circuit break-

Fig. 1 (Above)—Artist's conception of the Santee-Cooper Power and Navigation Project of the South Carolina Public Service Authority.

Fig. 2 (At Left)—Four of the six ultra-high-speed reclosing oil circuit breakers for Pinopolis power house, each rated 600 amp, 115 kv, 1,500,000 kva interrupting capacity.

Fig. 3 (Below)—Comparative reclosing speed graphs of pneumatic and solenoid operating mechanisms.



ers is 20 cycles measured from the energization of the trip coil, preparatory to opening, to the touching of contacts or reclosing.

The oil circuit breakers being supplied are of the down-break type, and the opening speed is about the same whether a solenoid or pneumatic operator is used because the opening speed is a function of the mass of the moving parts and the energy stored in the accelerating springs which were loaded by the previous closing. Hence, any decrease in reclosing time from the use of pneumatic operators must be obtained by decreasing the closing time.

Figure 3 shows the comparative reclosing speed graphs for the type of breaker being used for the control of the outgoing power from the Pinopolis plant. Curve A shows the reclosing characteristic obtained with a pneumatic operator; curve B, with a solenoid operator.

There are certain characteristics of the solenoid operator that make it difficult to improve curve B on this type of circuit breaker. The solenoid circuit is inductive, and it takes time to build up the magnetic field. It is possible to partly offset this time lag by energizing the solenoid before the breaker has fully opened. In the operation recorded in Fig. 3-B, the solenoid coil was energized four cycles before the end of the opening stroke.

Furthermore, the solenoid generally used in closing this type of breaker utilizes an armature which gets closer to the pole face and decreases the air gap as the breaker closes; hence, the greatest closing force is not at the beginning of the stroke when it is needed to accelerate the moving parts, but rather at the end of the stroke.

Advantages of compressed air operator

On the other hand, a pneumatic operator does not have these disadvantages. Large forces and mass inertias have to be overcome during reclosure, and it has been found that the air cushions the shock on moving parts. The speed and motion of the mechanism on the closing stroke can be accurately controlled by varying the area of the operating piston and the air pressure to give the best closing time. Because of the comparatively low inertia of the aluminum operating piston as compared to the energy stored in the compressed air, quick reversal of the breaker moving parts is obtainable, as shown in Fig. 3.

Since pneumatic energy is instantly available at full operating pressure, the maximum acceleration is obtained early in the closing stroke. As shown by the curves, the speed of the moving contacts is about the same for both solenoid and pneumatic operators at the time reclosure is completed; hence, no greater stresses are imposed on the breaker contacts. The speed of reclosing is practically constant during the stroke, and its rate permits substantially full opening of the breaker contacts during a standard 20 cycle ultra-high-speed reclosing operation.

Since the heavy work is done by compressed air, high-capacity storage batteries are not necessary. When the circuit breakers are mounted a considerable distance from the storage batteries, heavy leads are required, which are not needed for compressed-air operated breakers.

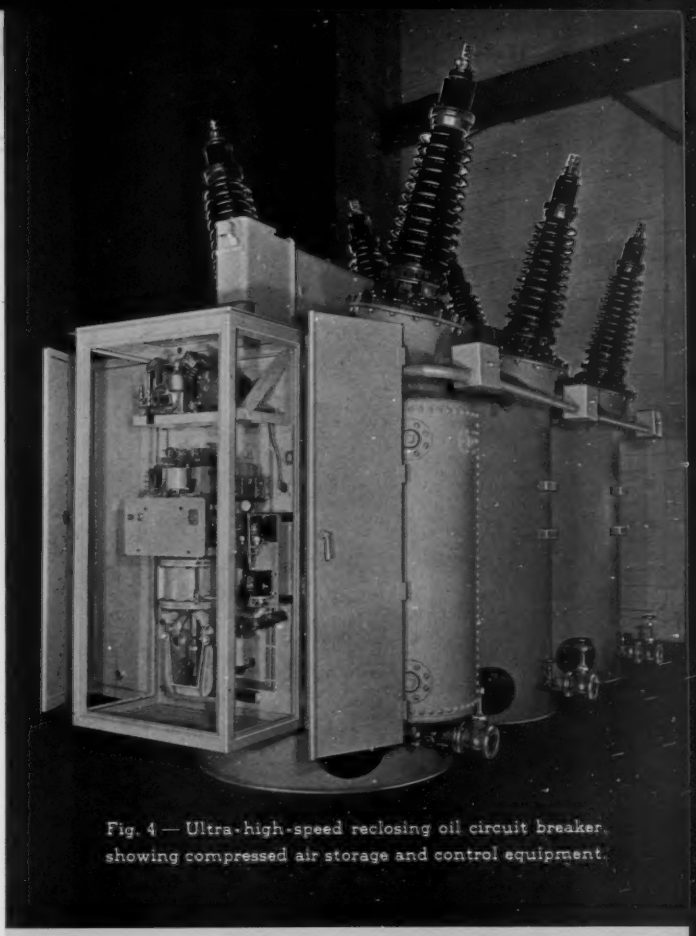


Fig. 4 — Ultra-high-speed reclosing oil circuit breaker, showing compressed air storage and control equipment.

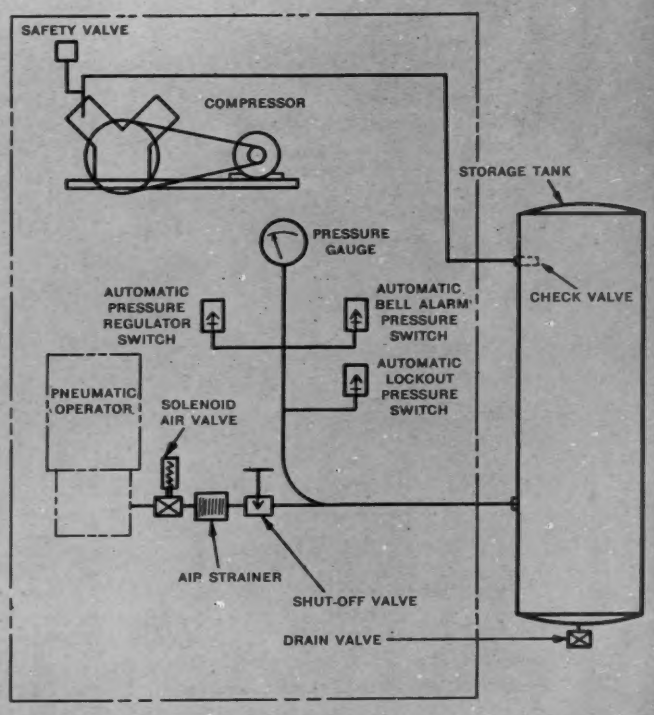
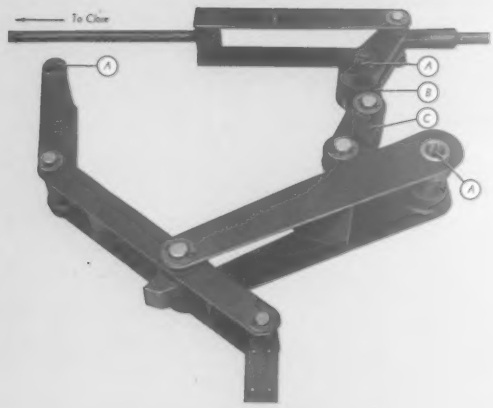
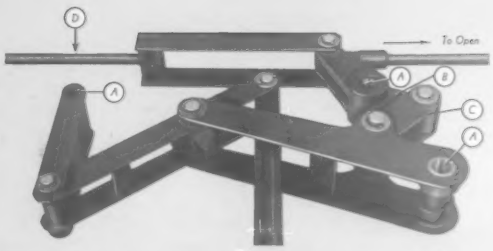


Fig. 5—Compressed Air Diagram for Pneumatic Operating Mechanism.



(a) Open



(b) Closed

Fig. 6 — Mechanical Linkage

Pneumatic equipment

The compressed air storage and control equipment used for operation of each of the three-phase breakers is shown in Fig. 4. All of the equipment shown within the chain dotted rectangle in the diagram, Fig. 5, is mounted within the breaker operating mechanism housing. The air storage tank is mounted adjacent to the operating mechanism cabinet and is attached to the front pole unit of the breaker.

The compressor mounted in the top of the control compartment automatically maintains the pressure between 110 and 120 psi. When the pressure falls to 85 psi, an alarm sounds; and, if the pressure should fall lower than 75 psi, a relay prevents the breaker from reclosing and sounds a two-tone bell. However, the storage tank has enough capacity to permit eight operations of the breaker before the pressure falls from 110 to 85 psi and eight more operations before the breaker locks out.

A safety valve, pressure gage, and shut-off valve are provided for safety and convenience. An air filter prevents foreign particles from entering the operating cylinder. For this installation duplicate 440 volt control feeders will bring power to operate the compressor motor. A 440/220 volt transformer and other control equipment are mounted in a weatherproof cabinet beside the pneumatic operator. Electric heaters are mounted in the control cabinet to keep the temperature above ambient and thus prevent condensation.

Because of the heating and cooling cycle during the compression of the air, there is a tendency for a little moisture to collect in the bottom of the compressed air storage tank. Provision is made for periodically draining off this water and for injecting anti-freeze in the winter time.

Mechanical construction

One operator actuates three sets of contacts; i. e., there is one operator for the three poles of one three-phase circuit breaker. The individual circuit breakers are mounted in separate tanks, and pull rods between the poles link the pole unit mechanisms to the operator.

On top of the pole is a mechanical linkage (Fig. 6) to convert the horizontal movement of the pull rod to straight-line vertical motion of the wood lift rod. In Fig. 6 the points labeled A are fixed centers. In Fig. 6(a) the contacts are in the open position, and in Fig. 6(b), closed. The toggle, consisting of crank B and link C, has a small offset in the open position and a large offset in the closed position to produce maximum mechanical advantage at the beginning of the closing stroke and maximum reaction tending to open the breaker at the beginning of the opening stroke. Both of these factors tend to improve the reclosing time characteristics.

An arrangement of compensating toggles in the operating and trip-free linkages lightens the loads on the holding and tripping latches when the breaker is in the closed position. The load on the tripping latch is so low that satisfactory tripping can be obtained with a coil having an E/R value of only 8 amperes at 250 volts. In order to promote high-speed recoupling, an auxiliary high-speed trip current cut-off contact, actuated by the trip coil, has been installed.

These oil circuit breakers are equipped with arc-enclosing devices for quick arc interruption. The movable bayonet-type contacts are of hard-drawn copper tube with solid contact tips of arc-resisting alloy and silver-plated contact surfaces. The movable bridging member and bayonet contact supports are of aluminum alloy for lightness. The lift rods are of straight-grained beechwood which is capable of withstanding a dielectric test of 100,000 volts for five minutes between two clamps 10 inches apart.

By using compressed air for operating the ultra-high-speed reclosing Pinopolis feeder breakers, an operating medium is provided that is positive, yet so flexible that it produces the high rate of acceleration of moving parts required without any intricate system of cams and levers. All practical safeguards have been taken to insure dependable operation, such as plenty of compressed air storage capacity in the tanks, duplicate sources of control-power supply, and low-pressure alarms. The pneumatically operated breakers performed very successfully during the exhaustive tests made before shipment, and it will be very interesting to watch their performance in the field.

SPECTROGRAPHY SPEEDS SCRAP SALVAGE

L. E. Royt

CHEMICAL RESEARCH LABORATORY • ALLIS-CHALMERS MANUFACTURING COMPANY

Calling on all resources, including the re-use of scrap metal, American industry adopts streamlined methods. With its fast, accurate detection of impurities, spectro-chemical analysis plays an important part in increased production.

The re-arming of America has called for a full utilization of all our resources; this can be exemplified by the conservation and re-use of scrap metals. To keep pace with modern, high-speed production using miscellaneous scrap material, modern chemical control analysis has had to adopt new streamlined methods. One of these is spectrochemical analysis, whereby minute amounts of sample material are electrically bombarded and the resulting light analyzed to show the chemical content.

A spectrographic installation is used for quantitative analysis of cast iron for control purposes and for qualitative and semi-quantitative analysis of miscellaneous material which is not used on a routine basis. Since such material may be variable and highly unpredictable in composition, analyses of the cupola content must be made at short intervals in order that the charge may be adjusted to compensate for drifts from the desired composition. It is imperative that such analyses be made and returned quickly to the metallurgist and cupola foremen before the drift becomes serious. There is another valuable use of this technique: if it should be desired to change the composition to a new value for a special job, analyses can be made in rapid succession until the adjusted charge is shown to have reached the well of the cupola.

The equipment involved consists of a grating spectrograph, spark power unit, pulsating d-c arc power unit, thermostated developing tray for photographic film processing, film dryer, photo-electric microdensitometer and comparator, and calculating board.

Preparing a sample

Every half hour as a ladle of iron is tapped from the cupola well, a clean sample is dipped by hand ladle and poured into a small iron chill mold which is so shaped that the metal is received in a reservoir of about 2 cu in. capacity and passes from it into four holes of ⅛ in. diam drilled to a depth of 1 in. below the bottom of the reservoir. Thus, upon cooling and removal, the block has four projecting pins which have been so rapidly chilled by contact with the metal mold that no opportunity for segregation of the components of the metal has been allowed.

Upon arrival at the spectrographic laboratory, two of these pins are broken off, the sides ground smooth, and one end of each ground slightly conical. These pins are then slipped into holders which in turn are placed in spring clamps, automatically bringing the axes of the two pins into coincidence. The conical ends are manually adjusted to form a 3/16 in. gap. Each pin is connected to one of the terminals of a spark power unit. This unit draws current from a 110 volt a-c line through the primary of a step-up transformer delivering a peak of 30,000 volts to the secondary circuit. The secondary circuit consists of a series group of inductance connected in parallel with a glass plate condenser bank, sample gap, and synchronous interrupter gap.

The voltage across the condenser follows that delivered by the transformer secondary winding. When the synchronized rotary gap comes into position, the condenser is discharged through the sample gap at an initial voltage corresponding to the phase of the a-c cycle at which the gap was closed. This allows adjustment of voltage impressed on the gap, insures that the voltage at which the spark initiates is inde-

In modern industrial laboratories, the spectrograph allows fast, accurate analysis of the composition of metallic materials.

Even minute traces of impurities can be quickly detected by spectro-chemical analysis.

pendent of the resistance of the air gap between the samples, and allows only the first few surges to pass on each half cycle. An air blast, directed upon the sample gap and blowing away the ions in that region, damps the discharge and minimizes the sputtering at the interrupter gap as the points separate after passing.

Method of analysis

The light produced in a spark is made up of a large number of wavelengths. Each element present produces its own group of characteristic wavelengths, the distribution of the light intensity among the various wavelengths being dependent upon the electrical conditions. It is therefore necessary that these be kept constant.

The path of the light used lies along the optic axes of the spectrograph, passing through a diffusing wire screen, through a Hartman diaphragm which defines the upper and lower boundaries of the beam, and through a bilateral slit 100 microns wide which defines the two sides of the beam. The light then passes on to a concave, aluminized speculum metal reflection grating which has 48,000 uniformly spaced vertical scratches in the space of 2 in. The light of each wavelength is reflected from this mirror grating along an individual path to the 35 mm movie film used to record the spectrum. Thus, at the film there is produced an image which consists of numerous vertical lines arranged on a horizontal strip. Each line is an image of the spectograph slit as produced by one of the many wavelengths present in the light from the spark gap.

This pattern has lines characteristic of all the elements present. The intensities of light in the lines characteristic of a given element will be dependent upon both the electrical conditions and the amount of that particular metallic constituent which is vaporized into the spark gap. Since the electrical conditions are fixed, the amount of the element vaporized is the only variable present, and that depends upon its concentration in the metal complex.

Thus, the ratio of intensity of a line due to silicon to the intensity of a line due to the iron matrix is a

measure of the ratio of the amount of silicon in the sample to the amount of iron.

The developed film is then placed in the densitometer comparator, and the lines to be measured are found and projected adjacent to a standard spectrum upon a screen on the wall. Light passes through the silver image in the film and through a defining slit 2 mm long and .0005 in. wide to a photoelectric cell. The electrons released by the light, striking the sensitive surface of the cell, are drawn by the plate voltage to the collector and to the grid of a triode power tube. This unbalances an electric bridge, causing a current to pass through a milliammeter.

Interpreting the results

The deflection of the meter is a measure of the light transmitted by the silver grain image in the film. By taking a film which has been given four different exposures related in a known ratio of, for example, eight-four-two-one, the deflection for each exposure can be plotted against the intensity of arbitrary units. If a double logarithmic plot is made of this, a curve is obtained which is closely analogous to the Hurter and Driffield curve usually plotted to relate photographic density and exposure. The density of any two lines, e. g., silicon and iron lines, can be read and the relative intensities determined from the curve by taking the difference of logarithms along the exposure axis corresponding to the two density values on the curve.

Spectrograms are taken of several sets of pins of which the silicon concentration is known by wet chemical analysis. The ratios of silicon line intensity to iron line intensity as determined above are plotted against percent silicon in the iron matrix. When this has once been done, a laboratory worker can take an unknown sample, spark, develop, read densities, convert to relative intensities, and read from the last curve mentioned the percent of silicon present. The curve may be dispensed with if use is made of a calibrated sliding scale, whereby relative intensities may be immediately converted to percent composition.

Advantages and limitations

Since each element has its own set of characteristic spectrum lines, this process may be performed upon all of the metal and metalloid constituents, using only a single exposure, since they all appear in the spectrum simultaneously. It is this advantage which gives the large labor and time efficiency factor of spectrographic analysis methods over wet analysis methods since the determination of each alloy constituent has to be made individually by the old wet chemical method of analysis.

The limitations of the spectrochemical method of analysis should be known. It is a powerful instrument on problems to which it is adapted. It cannot be used for work on non-metals, e. g., carbon and sulfur, because although they produce spectrum lines under certain conditions, these conditions are not convenient to achieve. Furthermore, calibration for quantitative work must be done on each constituent of an alloy, and this calibration is different for each matrix material, i. e., cast iron, copper, steel, etc. The time involved in the calibration pays only when a large number of samples are to be run as a matter of routine.

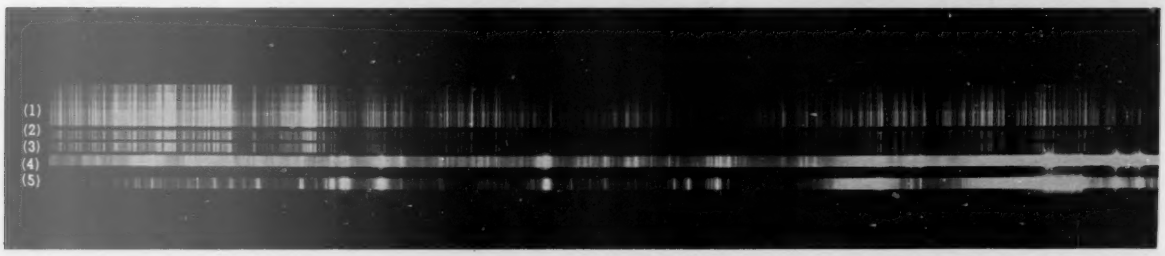
The spectrochemical method is most useful for determining low percentage constituents — five percent and below. Its accuracy surpasses wet chemical methods on very low percentage materials, such as undesirable contaminants.

Where the quantity of material is limited or the percentage of impurity is extremely low, as in some rectifier and feedwater deposits, ores, dust, and similar miscellaneous materials, the rectified arc unit is used to attain high sensitivity to small impurities. Semi-quantitative methods can be used, either synthesizing a range of powder mixtures and arcing them under the same conditions as the unknown in a pure graphite cup electrode, or synthesizing liquid mixtures and impregnating graphite electrodes with them.

The sensitivity and ease with which the complex mixtures can be analyzed is well illustrated by the following example: A dust sample from a foundry, containing 8 mg of inorganic residue on ashing, was arced and shown to contain iron, silicon, magnesium, calcium, barium, manganese, chromium, copper, aluminum, lead, tin, silver, zinc, titanium, traces of nickel and cobalt, and platinum which probably was picked up from the crucible in ashing.

Handled with discretion, the spectrograph is one of the most useful instruments at the command of a rapidly awakening industrial world.

Five spectra on one film (top to bottom)—(1) Stepped exposure spectrum for obtaining Hurter and Driffield contrast curve for the developed film. (2) and (3) Spark spectra of cast iron. (4) Arc spectrum of welding flux. (5) Standard powder spectrum.



PUBLIC USE IN PRIVATE, OR VICE VERSA

D. Journeaux

PATENT ATTORNEY • ALLIS-CHALMERS MANUFACTURING COMPANY

To be valid, a patent application must be filed within one year from the first "public use" of an invention. But "experimental use" is encouraged. Question: When is a use public, when experimental?

Complaints have often been made of the slowness of the procedure that inventors must follow before they can obtain the patents which should rather, in their minds, be pressed upon them. Yet one of the purposes of the patent system of this country is to give to the public the benefit of disclosures of inventions at as early a date as possible. Indeed, the history of our patent laws seems to reveal a series of attempts to determine, by a method of successive approximations, just how soon prospective patentees can be required to file their applications after completing their inventions.

One year public use

At present a valid patent on an invention cannot be obtained unless the application be filed within one year from the first public use or sale of the invention in the United States. Formerly the length of this period was two years. The thought back of this limitation of public use is that the public should not suddenly see itself deprived of an invention after having enjoyed the unrestricted use of it for a period of years. In this respect a patent assumes a certain similarity to real property; and it was held in a suit for infringement that, if an inventor allows the public at large to use his improvements for many years, "he must be deemed to have made a gift of them to the public, as much as a person who voluntarily opens his land as a highway, and suffers it to remain for a length of time devoted to public use."

The law, at least since its revision in 1870, is perfectly clear as to this requirement. Yet its application has been found so full of difficulties that it has been disregarded by numerous patentees, who were often apparently quite unaware of being tardy.

What is public use?

Naturally, before different aspects of public use are examined, the question arises, just what does constitute a public use? As is often the case in patent law, a too general definition is dangerous in that it may be inapplicable to some unforeseen set of circumstances. With due caution it may be considered that an invention is in public use when it is used openly by the inventor for its intended purpose and also when it is used by any one beyond the control of the inventor. To apply this rule to any particular instance of use, it is, however, always necessary to bear in mind the explanatory statements made by the courts and the conclusions reached in cases involving similar states of facts.

Experimental use

Taken literally, the public use statutes were always quite inflexible. It was not very long, however, before inventors, or more probably, their counsel, had the brilliant idea that, if a public use of an invention for more than two years (now one) before filing is a bar to the grant of a patent, there is no reason why some other kind of use could not take place at that time without having such an effect. The most frequent example of innocuous use is experimental use, which has served many times as an excuse for delay during the last six or seven decades. While in many instances a long use of an invention cannot reasonably be interpreted as being experimental, a well proven experimental use made in good faith has often been held by the courts not to be a public use. The authority for this policy is the Supreme Court, which stated that:

> "It is sometimes said that an inventor acquires an undue advantage over the public by delaying to take out a patent, inasmuch as he thereby preserves the monopoly to himself for a longer period than is allowed by the policy of the law; but this cannot be said with justice when the delay is occasioned by a bona fide effort to bring his invention to perfection, or to ascertain whether it will answer the purpose intended. His monopoly only continues for the allotted period, in any event; and it is the interest of the public, as well as himself, that the invention should be perfect and properly tested, before a patent is granted for it."

Profits from experimental use

Litigants in patent suits have often made legal history out of the fact that experimental use and use for profit may be hard to distinguish, and a use in public may even serve both as an experiment and as a source of revenue. Naturally, if a patentee happened to put his invention to any use at all before the period allowed by law, an infringer will solemnly assert that the use was public and that it invalidates the patent, while the patentee will contend no less strenuously that the use was experimental and hence permissible. The Supreme Court, therefore, went one step further in an attempt to bring order out of this chaos, and stated that:

> "A use by the inventor, for the purpose of testing the machine, in order by experiment to devise additional means for perfecting the success of its operation is admissible; and where, as incident to such use, the product of its operation is disposed of by sale, such profit from its use does not change its character; but where the use is mainly for the purpose of trade and profit, and the experiment is merely incidental to that, the principal and not the incident must give character to the use. The thing implied as excepted out of the prohibition of the statute is a use which may be properly characterized as substantially for purposes of experiment."

Experimental use must be proved

Although the grant of a patent is not accompanied by a guarantee of validity, it is a general rule that a patent is assumed to be valid until sufficient reason is shown in court why it should not have been granted. An infringer, who would establish that a patent is invalid because the invention claimed therein was in use before the permissible period, must furnish full and convincing proof of it. If he succeeds in doing so, what will the court do on the basis of his evidence? The answer was well formulated in a court decision stating that:

> "Instead of laying down a fixed rule, it seems to us that in each case the court should direct its attention to the fundamental inquiry: Under what circumstances and for what purpose did the public use or sale take place? And, where it appears that there has been a public use or sale more than two years before the application, the burden is thrown upon the patentee to establish, by full, clear, and convincing proofs, that such use or sale was principally and primarily for experimental purposes, and that such purposes were not merely incidental or subsidiary. Whatever expressions may be found in the opinions of the Supreme Court to the effect that a single sale comes within the statutory prohibition, we think a careful examination of the cases shows that the primary and governing consideration is the purpose and object of the inventor in making such sale."

The question whether an invention was in public use or in experimental use, while depending on the inventor's intentions, resolves itself into a question of fact. The inventor's intentions are, no doubt, often obscure or nebulous, and his testimony regarding them after a number of years is, at best, unreliable. Facts carrying out these intentions, however, can be proved by witnesses, and the inventor may then be credited with whatever intentions are consistent with his actions. If his acts and his professed intentions were not in accord, he deserves little sympathy and will probably receive none.

Experimental use in public

If an inventor decides beforehand that the first use of his invention will be experimental, making his intentions clear to all persons involved in such use, and conducts the use as an experiment, that use may extend over a number of years without invalidating a patent subsequently applied for. Most cub patent attorneys cut their legalistic teeth on one instance of such use, which is famous for its extreme length and publicity as well as for the masterly explanation of the law that it occasioned.

The invention in question, shown in Fig. 1, consists of a pavement of wooden blocks with wide joints filled with a mixture of tar and gravel and laid on a waterproof foundation. Upon being sued, an infringer pleaded the patent was invalid because a 75-foot strip of the pavement had been used by the public for six years before the patentee filed his application. This strip was installed in 1848 by the patentee, at his own expense, on a toll road owned by a corporation of which he was treasurer. The patentee made it clear, from the beginning, that it was experimental, and he inspected its condition himself almost daily.

Fig. 1 — S. Nicolson's wooden pavement, first used experimentally in 1848. The patent, which was applied for six years later, was nevertheless valid.

In view of these circumstances, the Supreme Court in 1878 held that there was no public use of the invention and that the patent was valid. Thus was born the paradox of an invention being used by the public for years without being in "public use." But, as an experimental use on that scale was unprecedented, the Court based its decision on the established rules governing the public use of machines, of which it said:

"When the subject of invention is a machine, it may be tested and tried in a building, either with or without closed doors. In either case, such use is not a public use, within the meaning of the statute, so long as the inventor is engaged, in good faith, in testing its operation. He may see cause to alter it and improve it or not. His experiments will reveal the fact whether any and what alterations may be necessary. If durability is one of the qualities to be attained, a long period, perhaps years, may be necessary to enable the inventor to discover whether his purpose is accomplished."

Public use in private

Going from one extreme to the other, the same court, in 1881, declared another patent invalid in a decision which has set, for generations of patent attorneys, the standard of non-permissible use. This decision also gave us the second paradox of an invention being in "public use" merely because it was used privately by one person other than the inventor. The invention in litigation is shown in its pristine simplicity in Fig. 2. It is a double leaf corset spring which, at the time of its invention in 1855, no doubt deserved considerable attention. It was devised to replace the disconcertingly breakable single leaf springs then currently in use and to give to the feminine body the softly resilient support now more generally provided for automobile bodies.

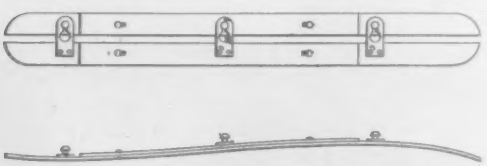


Fig. 2 — S. H. Barnes' double leaf corset spring, invented in 1855 and first patented in 1866. The patent, reissued five times, was finally held invalid because of prior use of the invention by one person.

The inventor made some springs and gave them to his future wife to be used by her, but without enjoining her to keep his idea secret. Apparently he did not have in mind that such use be made under his direction as a scientific experiment. In 1866, when the inventor applied for his patent, the springs had somehow, it is stated, gained general acceptance by the trade. But the patentee was too late to gather his reward. In the words of the Supreme Court, the inventor slept on his rights for eleven years. Like Rip van Winkle, he found on awakening that what once belonged to him had passed to others. His patent, to which he belatedly gave so much attention that he and his wife reissued it five times, was held invalid. The general principles of this holding were laid down as follows:

"To constitute the public use of a patent it is not necessary that more than one of the patented articles should be publicly used. . . . Whether the use of an invention is public or private does not necessarily depend upon the number of persons to whom its use is known. If an inventor, having made his device, gives or sells it to another, to be used by the donee or vendee, without limitation or restriction, or injunction of secrecy, and it is so used, such use is public, within the meaning of the statute, even though the use and knowledge of the use may be confined to one person."

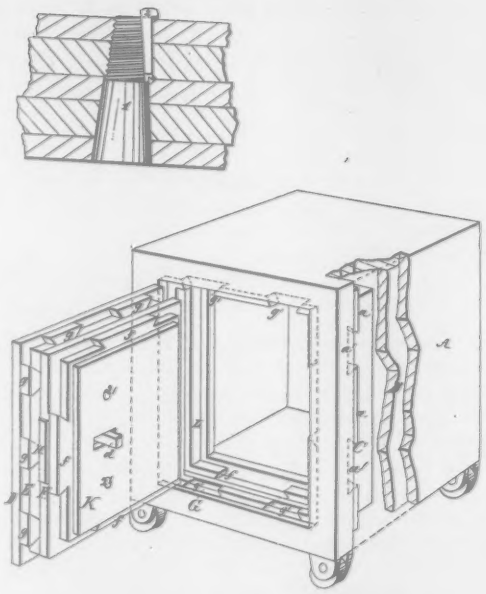


Fig. 3 — J. L. Hall's burglar-proof safe patented in 1867. One claim of the patent was invalidated by prior use of the invention although the invention could not normally be detected.

Public use beyond knowledge of user

Use beyond the knowledge of the general public was also fatal to a claim of a patent on the safe construction shown in Fig. 3. The claim was directed to the tapered bolts used for fastening together the plates forming the casing and the door. The patentee made and sold outright a few of these safes more than two years before applying for the patent. The invention embodied in those safes was held in 1883 to be in public use for the reasons that:

"The construction and arrangement and purpose and mode of operation and use of the bolts in the safes were necessarily known to the workmen who put them in. They were, it is true, hidden from view, after the safes were completed, and it required a destruction of the safe to bring them into view. But this was no concealment of them or use of them in secret. They had no more concealment than was inseparable from any legitimate use of

them. As to the use being experimental, it is not shown that any attempt was made to see if the plates of the safes could be stripped off, and thus to prove whether or not the conical bolts were efficient. The safes were sold, and apparently no experiment and no experimental use were thought to be necessary. The idea of a use for experiment was an afterthought. An invention of the kind might be in use, and no burglarious attempt be ever made to enter the safe; and it might be said that the use of the invention was always experimental until the burglarious attempt should be made, and so the use would never be other than experimental. But it is apparent that there was no experimental use in this case, either intended or actual."

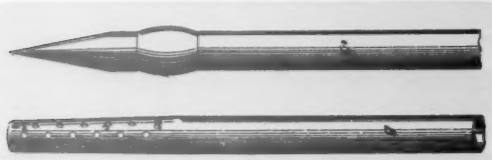


Fig. 4 — N. W. Green's driven well invented in 1861, patented in 1868. The patent was held invalid because of prior public use of the invention based on information given by the inventor.

Public use of process

The litigation involving the so-called driven well patent distinguished from the above cases in that the patent was for a process and in that the patentee had no participation in the public use which defeated the patent. The latter claimed the method of making a well by driving the well casing into the ground or by first driving a mandrel which is then replaced by the casing. This method had considerable merit, and it is still standard practice for procuring drinking water in rural communities. Both mandrel and casing, shown in Fig. 4, may have been new when the inventor provided them with his process in 1861, but he did not claim them as his invention.

Soon after inventing his method he demonstrated it in public, and within the next few years wells were driven by some who either had witnessed his demonstration or heard of it. Unfortunately, the patentee delayed applying for his patent until 1866, and in 1887 the patent was held invalid because the driving of the wells constituted a public use of the invention outside of the permissible period. The fact that the invention would not be readily apparent upon inspection of the finished wells was immaterial since it had been used by the makers of the wells, who were members of the public.

Public use of material

Likewise a material used in the manufacture of articles of commerce is in public use even if its processing has rendered its composition unrecognizable. Thus, in 1928, an infringer of a patent for a rubber composition comprising a particular type of vulcanization accelerator pleaded that an accelerator of that type had been used in the manufacture of rubber tires more than two years before the patent was applied for in 1914. The accelerator was destroyed by the vulcanization process before the tires were sold to the public, and there was no way of learning from the finished tires either their composition or the process by which they had been made. Could such use of the material be public? The court answered:

> "This was the only kind of use possible and it was public. . . . Once the invention has been embodied in goods which are put in public use it becomes impossible for a later inventor to secure a patent."

Experimental use disproved

Another invention which had an element of inaccessibility was the cable railway track illustrated in Fig. 5. The inventor designed this arrangement in 1876 for a short line which began operating in 1878, more than two years before he applied for a patent. When suing an infringer in 1892, the inventor argued that this installation was experimental because its construction was still untried; and, therefore, he had doubts as to its permanency. But the circumstances of this use were not similar to those of the pavement case previously considered. The court therefore disagreed with the inventor, stating that:

> "He did not treat it as an experimental thing, but allowed it to be appropriated as a complete and perfect invention, fit to be used practically, and just as it was, until it should wear out or until it should demonstrate its own unsuitableness. He turned it over to the owners without reserving any

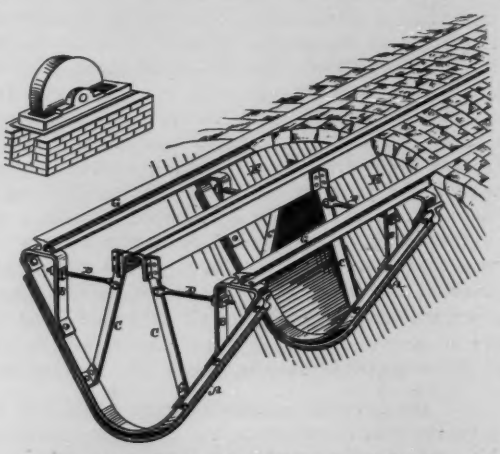


Fig. 5 — H. Root's cable railway foundation, invented in 1876, patented in 1882. The patent was held invalid because prior use of the invention could not be proved to be experimental.

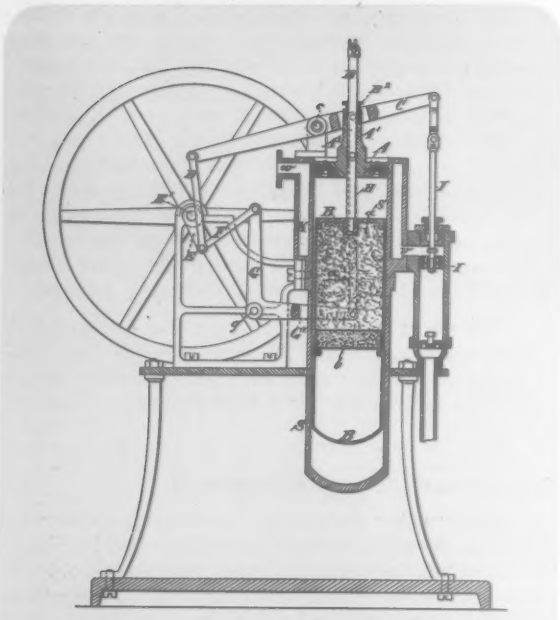


Fig. 6—J. Ericsson's hot air engine of 1877, patented in 1880. The patent was invalidated by prior use of the engine beyond the control of the inventor.

future control over it, and knowing that, except as a subordinate, he would not be permitted to make any changes in it by way of experiment."

No experimental use after unrestricted sale

Equally unsuccessful was the assignee of a patent for the engine shown in Fig. 6. This engine, operated by hot air, was similar to some toy engines still sold today, but of a species apparently otherwise extinct. It embodied a water pump discharging through the water jacket of the engine cylinder. Several engines were sold outright and installed in Manhattan by the patentee's assignee for pumping water into the attic tanks of residences, a job otherwise incumbent upon the house coachman. At least one engine installed in 1877 was frequently inspected and repaired, sometimes without cost, by the manufacturer. The engine efficiency however was not guaranteed, and there was no agreement to take it back. After seven years' use it was traded in as part payment for a new engine of similar construction. In an infringement suit it was argued that such a set of circumstances was evidence of experimental use. But the court held in 1893 that the engine had been in public use, stating that:

> "If the inventor wishes to keep control of the machine which embodies his invention, to secure his own access to it for examination, and to keep it in the friendly hands of those who, he intends, shall aid him by practical experiment, he must make such restrictions a part of the contract of sale, and the court cannot assume them to exist in the absence of proof."

Public use in experimental system

The carbon brush, which has assumed considerable importance in the manufacture of electric motors, is also notable for the peculiar circumstances which led to invalidation of the basic patent granted for it. Fig. 7 shows one of the constructions illustrated in the patent. In 1881 the inventor tried replacing the then current copper brushes by carbon pieces. Later he devised an overhead conveying system utilizing a car running on a cable and propelled by an electric

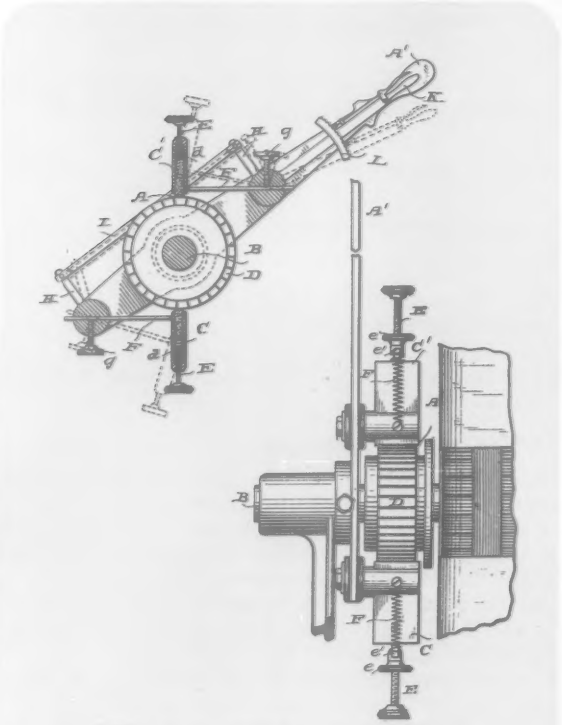


Fig. 7—C. J. Van Depoele's carbon brush for electric motors, invented in 1881, patented in 1888. The patent was held invalid because of prior public use by the inventor in an experiment other than to test the brushes.

motor. An experimental model of this novel system, driven by a motor provided with carbon brushes, was built in 1885 for the sole purpose of demonstrating its operativeness. The inventor did not need to experiment with the carbon brushes, as he had already found them satisfactory years before. The motor simply did its duty as a motor, and there was nothing experimental about it. Were then the brushes in public use? The court denying the validity of the patent in 1901 found that:

> "There is no dispute on the proof as to what this use was. As to a system for overhead elec-

trical transportation it was experimental, but as a use of carbon brushes in combination with a segmental commutator on an electric motor it was a substantial public use . . . it was a practical use of the invention, since the motor was used occasionally to propel the car in connection with the experiments on the cable system, which the apparatus was intended to embody."

Such was the history of the third paradox of an invention being in public use in an experimental system.

Experimental use should be planned

The passages above quoted were taken from only a few of a long line of decisions which seem to be relatively free of the apparent or real contradictions often found between court decisions based on different sets of circumstances. It may be deduced from them that an invention will not be held to be in public use if it really requires experimentation at the time of its being used and if the inventor makes it clear that such is his purpose in using it.

With a view to possible future patenting of the invention, it is, therefore, advisable to make it of record that an experimental use is intended even before such use is begun. Any agreements that may be necessary should be reached beforehand with the users of the invention to insure that it remains under the full control of the inventor or of his assignee for experimental purposes. Last but not least, the use should be actually conducted as an experiment, and records made of observations from which the desirability of changes or the suitability of the structure under test will be apparent.

Prompt filing advisable during experimental use

It is seldom, however, that an experimental use of a complete invention needs to last as long as one year to determine whether the invention will perform satisfactorily. In general it will be possible to file a patent application on the fully tested invention within one year from the beginning of experimental use. If it is desired to subject the invention to a life test under actual operating conditions or even under abnormally adverse conditions, the experiment may extend over a period of years.

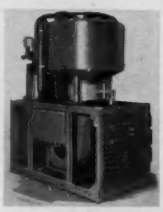
Although application for a patent may still be delayed until the test is completed, nevertheless the inventor may save himself a considerable amount of trouble in establishing or asserting his patent rights by filing his application within one year from the beginning of the experiment. Of course, any protection that he may seek by a patent will be limited to whatever features of his invention were in his mind at the time of filing his application. But if continuance of the test suggests to him some valuable improvements, he may still protect them by other patent applications.

Regulators for Low Capacity Lines

Station type feeder voltage regulators with 5/8% steps are now available in 12 and 24 kva capacities for 2400 and 4800 volt lines. Formerly only wide-band branch type regulators were built for this low-capacity service, but now the new low-cost 12 and 24 kva units make station type regulators available for serving small branch feeders.

Features of the new regulators that were formerly available only in larger ratings are narrow voltage band width, low losses, low exciting current, and reduced maintenance. The voltage can be held within 5/8 of 1% of the nominal value. The regulators are also offered in 17.3, 34.5, and 69 kva capacities for 6900 volt service.

Air-Cooled Mercury Arc Rectifier



For converting alternating current to direct current in locations where the use of cooling water is expensive or unsatisfactory, an air-cooled mercury arc rectifier is now available in 400, 600, and 750 ampere capacities. The high overload capacity of this unit makes it especially useful for supplying power to machine tools, cranes, haulage apparatus, street cars, trolley buses, and other fluctuating loads.

The rectifier has the conventional arrangement of six shielded main anodes suspended from an anode plate over a mercury cathode inside a metal vacuum chamber. Around the rectifier is a cooling jacket through which air is conducted from a blower mounted underneath. Fins on the walls of the cathode housing, vacuum chamber, and anode plate increase the heat-radiating area. Gaskets of a special rubber compound seal the vacuum chamber.

The whole unit consisting of the rectifier, blower, evacuating and arc ignition equipment is assembled and wired in the factory and is shipped ready to be connected into the circuit.

For further, more detailed information regarding these new products, write the Editors of ELECTRICAL REVIEW.

ON FOLLOWING PAGES: Rough machining a forging for a 32,000 kw, 1500 rpm, reaction, single cylinder, condensing steam turbine.

INTERPRETATION OF TIME-TEMPERATURE CURVES OF ROTATING MACHINES

Fraser Jeffrey & R. M. Osborn

ELECTRICAL DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

Modern rotating machines are designed to take sudden overloads. However, if too much heat is generated, something breaks down. Here is a method of calculating the extent and time of permissible operation beyond rated load.

In order to apply protective relay devices properly to safeguard rotating machines such as motors or generators, it is essential to know something of their time-temperature characteristics during starting and under normal running conditions, as well as under conditions of intermittent or occasional overload. Knowledge of these characteristics is necessary in order to establish the short-time ratings of machines at loads higher than the load which can be carried continuously without exceeding a given temperature rise. This paper deals only with temperatures under running conditions since it is felt that the question of temperatures under starting conditions is so distinctly different and so varied in scope that it warrants an entirely different method of approach than that used here.

Despite existing literature on the subject of short-time ratings, the published data on the actual variation of machine temperatures with time is meager. Following is a description of the nature of time-temperature characteristics of actual machines and a development from actual tests of a logical basis for the rating of such machines for short-time overloads.

The establishment of time-temperature curves based on actual test data derived from embedded temperature detectors rather than thermometers, the theoretical rate of rise of copper, or other apparently logical assumptions make possible a more accurate determination of the time-temperature limitations of any given machine, under any number of other different loadings, than has heretofore been available.

The tests described were made on a number of large 3600 rpm squirrel-cage induction motors that happened to be available. All machine temperatures were measured by means of resistance detectors embedded in the slots between the upper and lower stator coil sides in the central part of the stator core. This method of temperature measurement is generally recognized as giving the closest to the "hottest spot" temperature obtainable by test.

Theoretical single exponential curve

The simplest theoretical case involving the rate of temperature rise of a body is that in which the amount of heat being added to the body is constant, while the amount of heat being carried away from that body is proportional to the temperature rise of the body above ambient temperature. A typical example is a copper conductor carrying current and being cooled by the air at the surface of the copper.

In this case the temperature of the body at a given time can be expressed by an exponential equation[8, 32, 35] of the form

$$\frac{y-y_o}{Y-y_o}=1-\varepsilon^{-t/\tau} \tag{1}$$

where y = temperature rise above ambient at time t.

y_o = temperature rise above ambient when $t=0$.

Y = ultimate rise above ambient when $t=\infty$.

τ = thermal time constant.

The thermal time constant τ is given by

$$\tau=k/s \tag{2}$$

where k = thermal capacity per degree rise
= specific heat × weight of body.

s = dissipation from surface per degree rise
= dissipation per unit area × surface area.

If the temperature of the body at a given time is expressed as the percentage of the difference between the initial and ultimate rise, the curve of time vs. temperature will be that illustrated in Fig. 1. This curve has the interesting property that a tangent to the curve at any point intersects the ultimate rise at a point one time constant farther to the right than the point of tangency to the curve. This property

gives a rapid method for estimating the time constant of an exponential curve.

This curve becomes a straight line if plotted on inverted semi-logarithmic paper as shown in Fig. 2.[35] If test points are so plotted and if a straight line can be drawn through the test points, it is known immediately that the curve is exponential. Furthermore, the slope of the straight line determines the time constant, and an equation for the curve similar to equation (1) can be written. It should be noted that the ordinate scale is compressed at the low values and expanded at higher values. It is therefore much more important to fit the test curve to the test points at the lower portion than the upper portion of the curve. When plotted in this manner, a test point in the upper region may appear to be rather far off the curve and yet be very close in actual degrees because of this exaggeration in the upper portion of the ordinate scale.

If the time-temperature characteristic follows an exponential curve, the binary time constant[30, 35] at 50% of the total rise will be

(3) $\tau_b = 0.693\,\tau$

so that, if the time-temperature curve is established, the thermal time constant, τ, can readily be ascertained as shown by Fig. 1.

Conversely, if τ is known, then the time-temperature curve, as shown by Fig. 1, can also be readily ascertained by the use of equation (1).

It must be recognized that an exponential time-temperature curve theoretically never actually reaches the ultimate temperature rise line but closely and indefinitely parallels it. Practically, however, constant temperature in all cases is assumed to be reached when the exponential curve appears to merge into the ultimate temperature rise line.

The initial rate of heating of the body is dependent entirely upon the rate at which heat is being added and the thermal capacity of the body since no heat is carried away when the body is at ambient temperatures. The initial rate of rise is easily calculated in simple cases. The thermal time constant can be expressed in terms of the initial rate of rise as follows:

(4) $\tau = \dfrac{Y}{\alpha}$

where $\alpha = \dfrac{dy}{dt}$ when $y = t = 0$,

(5) α = (heat loss in body)/k

This equation is useful in calculating the thermal time constant when the ultimate rise Y is known (preferably from test) and when $\dfrac{dy}{dt}$ is known from test or can be calculated accurately.

When the heat is generated in copper by the flow of current, substitution of the specific heat of the copper and the loss per pound of copper for a given current density in equation (5) gives the following equation, based on copper at 75 C:

(6) $\alpha = 0.867 \times$ (kiloamperes per sq in.)^2

where α = deg C per min.

When the heat is generated in iron by the hysteresis and eddy current loss caused by the alternating flux, the initial rate of rise can be expressed in terms of the specific heat of the iron and the heat loss per unit weight of iron, resulting in the following:

(7) $\alpha = 0.275 \times$ (watts per pound)

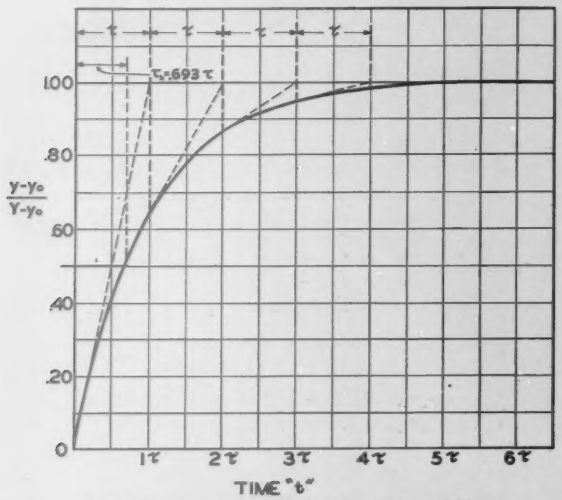


Fig. 1—Single Exponential Variation of Temperature with Time

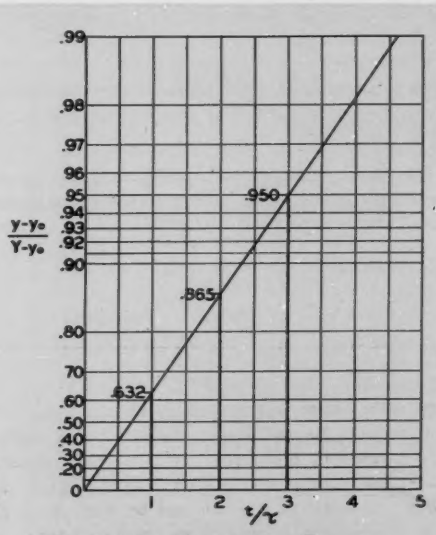


Fig. 2—Time-Temperature Curve on Inverted Semi-Logarithmic Paper

The watts per pound is a direct function of the flux density for the particular iron involved.

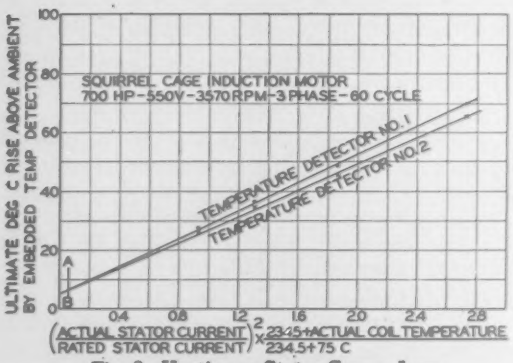
For normal values of current and flux densities in alternating current machines, the rate of rise obtained by equation (6) is several times as great as obtained from equation (7). For a given temperature rise, the time constant of the copper is, therefore, much shorter. Since the losses in an actual machine are in both the copper and iron, the average time constant of the machine should be expected to fall somewhere between these limits; and this proves to be the case.

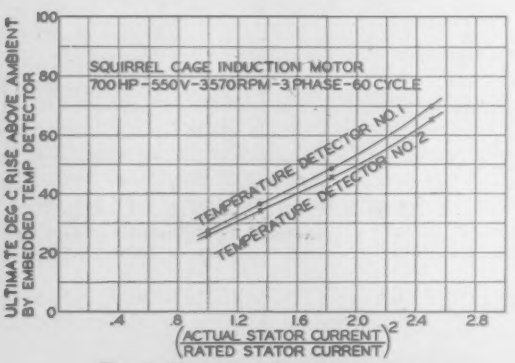
The expression or approximation of an actual time-temperature curve by a single exponential equation of the type described above is convenient because the entire time-temperature variation is completely determined by two quantities — the ultimate rise and the thermal time constant. The ultimate rise of electrical apparatus is universally accepted as the most important criterion for the continuous rating of the apparatus. It is therefore possible, in the case of this type of temperature variation, to give a complete picture of the ability of the apparatus to carry occasional or intermittent overloads, so far as temperature is concerned, by specifying one additional quantity; viz., the thermal time constant. Other factors, such as stability, may limit the load to a lower value than that determined by the maximum allowable temperature rise.

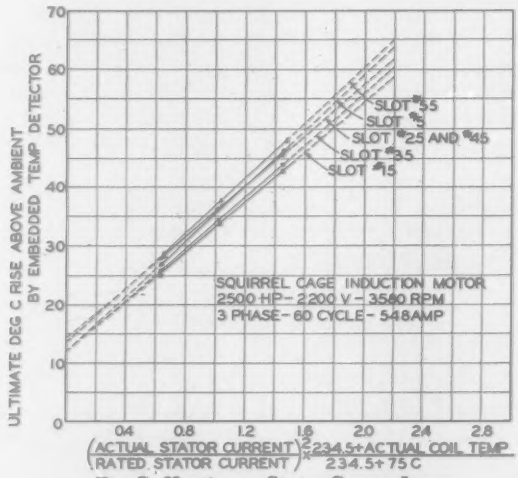
Theoretical double exponential curve

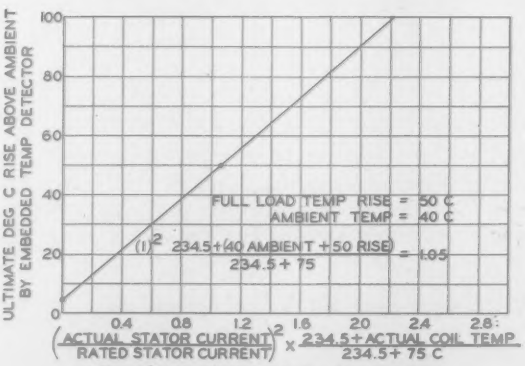
Unfortunately, the complexity of temperature distribution in a rotating machine is such that it is often difficult or impossible to fit a test curve with a single exponential equation. A rotating machine consists principally of magnetic steel, copper, and insulation. There is heat generated both in the copper and the iron, and there is a temperature difference between the copper and the ventilating air, between the iron and the ventilating air, and between the iron and the copper. Consequently, a transfer of heat from both the copper and the iron to the air and from the copper to the iron (or sometimes from the iron to the copper) occurs. This heat transfer between the iron and the copper and the harder working of the copper than the iron cause the deviation from a true exponential curve.

The theoretical variation of temperature with time in the case of two bodies in which heat is generated is found by assuming that the heat transferred from each body is composed of two components: one, that transferred to the cooling medium, is proportional to the temperature rise of that body above ambient temperature; and two, that transferred to or from the other body, is proportional to the difference in tem-


ULTIMATE DEG C RISE ABOVE AMBIENT BY EMBEDDED TEMP DETECTOR
SQUIRREL CAGE INDUCTION MOTOR
700 HP-550V-3570RPM-3 PHASE-60 CYCLE
TEMPERATURE DETECTOR NO.1
TEMPERATURE DETECTOR NO.2
A
B
(ACTUAL STATOR CURRENT / RATED STATOR CURRENT)² x 234.5+ACTUAL COIL TEMPERATURE / 234.5+75 C
Fig. 3—Heating vs Stator Copper Loss


ULTIMATE DEG C RISE ABOVE AMBIENT BY EMBEDDED TEMP DETECTOR
SQUIRREL CAGE INDUCTION MOTOR
700 HP-550V-3570RPM-3 PHASE-60 CYCLE
TEMPERATURE DETECTOR NO.1
TEMPERATURE DETECTOR NO.2
(ACTUAL STATOR CURRENT / RATED STATOR CURRENT)²
Fig. 4—Heating vs Stator Current


ULTIMATE DEG C RISE ABOVE AMBIENT BY EMBEDDED TEMP DETECTOR
SLOT #5
SLOT #3
SLOT #25 AND #45
SLOT #35
SLOT #15
SQUIRREL CAGE INDUCTION MOTOR
2500 HP-2200 V-3580 RPM
3 PHASE-60 CYCLE-548AMP
(ACTUAL STATOR CURRENT / RATED STATOR CURRENT)² x 234.5+ACTUAL COIL TEMP / 234.5+75 C
Fig. 5—Heating vs Stator Copper Loss


ULTIMATE DEG C RISE ABOVE AMBIENT BY EMBEDDED TEMP DETECTOR
FULL LOAD TEMP RISE = 50 C
AMBIENT TEMP = 40 C
(1)² 234.5+(40 AMBIENT +50 RISE) / 234.5+75 = 1.05
(ACTUAL STATOR CURRENT / RATED STATOR CURRENT)² x 234.5+ACTUAL COIL TEMP / 234.5+75 C
Fig. 6—Heating vs Stator Copper Loss

perature between the two bodies. On these assumptions, the temperature of either body may be expressed as a double exponential[34] of the form

$$(8) \qquad \frac{y-y_o}{Y-y_o}=a_1\,(1-\varepsilon^{-t/\tau_1})+a_2\,(1-\varepsilon^{-t/\tau_2})$$

where τ_1 and τ_2 are time constants, and
a_1 and a_2 are fractions of total temperature change governed by each time constant.

$a_1+a_2=1$.

This equation involves two more parameters than the single exponential equation: an additional time constant and the division of the ultimate temperature change $(Y-y_o)$ into two parts, $a_1(Y-y_o)$ and $a_2(Y-y_o)$, with different time constants.

The number of parameters in this question is so great that almost any test curve of temperature vs. time can be closely approximated by an equation of this type. It involves more labor, however, to determine the various parameters from the test curve. Furthermore, it is exceedingly difficult to correlate a set of tests in such a manner that the parameters vary in a consistent manner in order to make possible the prediction of the characteristics of a machine not yet built or on which sufficient test data are not available.

Actual time-temperature tests

In order to specify the time-temperature characteristics of a machine under a given load, it is necessary to determine the ultimate rise at that load and to fit the time-temperature curve with some curve or equation similar to the theoretical curves described in the foregoing discussion. It is usually undesirable or impossible to determine the ultimate rise at that load directly from test since injurious heating may occur if the machine is allowed to reach its ultimate temperature at a load intended to be carried only for a short time. The ultimate rise is best found by extrapolating from tests at lower loads.

Theoretical considerations and long experience show that the temperature rise of the coils can be expressed over a wide range of loads as the sum of two quantities—one fixed and the other proportional to the copper loss in the coils. This is illustrated by Figs. 3 and 5, which show the results of tests on two 3600 rpm squirrel-cage induction motors, which were run until constant at various loads, and the results plotted as shown. The abscissa is exactly proportional to the stator copper loss. Finding the rise at a given load from these curves involves a small amount of trial and error since the rise must be known before the abscissa is determined. This trial and error can be eliminated by replotting the curves of Fig. 3 and omitting the percent coil temperature multiplier. The result is then shown by Fig. 4.

Over a small range in temperature, the curves plotted as indicated in Fig. 4 are nearly straight lines; hence, over small temperature ranges or as an approximate method, the correction for temperature may be omitted, and rise plotted simply as a function of the square of the current. For synchronous machines operating at constant power factor, the current is very nearly proportional to the load, and the rise may be plotted against the square of the load. This method introduces some error in the cases of induction motors or synchronous motors operated with constant excitation because of the variation in power factor with load.

It should be noted that the straight line curves in Fig. 3 intersect the vertical ordinate at zero stator current at 5 C ultimate rise and do not pass through the origin. This is because of the fact that, when the motor is running idle at its normal voltage and frequency and is not carrying any current at this theoretical intercept, there is some temperature rise in the motor because of the core loss and windage and friction. In the case of an induction motor, of course, this intercept is only theoretical since normal voltage cannot be attained without the flow of a certain amount of magnetizing current. When consideration is then given to this latter factor, the idle running temperature rise is then 6 C as shown by the intercept of the curve with the line AB, which represents the abscissa value of the magnetizing current. It must also be recognized that the temperature rise at the intercept ordinate for zero current will vary considerably, probably from 5 C to 15 C or more for different machines, and this must be given consideration when assigning values to y_o as used in equation (11).

In order to ascertain accurately various thermal limitations for any given machine, it is essential that a time-temperature test curve, at some particular loading, be available on the machine in question or one similar to it. From such data, the temperature can be ascertained for any other loading for any given time. In other words, if it is assumed that the temperature rise of a motor under continuous full load is 50 C by embedded temperature detector, whereas in actual test the rise is only 35 C by embedded detector, then the motor is much more liberal in its heating limitations than would be the case if the assumed value were used.

It is possible to predetermine, from either an assumed or an actual time-temperature test, all the other temperature limitations of the motor with respect to any other load conditions.

Figure 6 has been drawn to show ultimate temperature rises for various loads, based on a temperature rise by embedded detector at full load of 50 C and an ambient temperature of 40 C. In drawing this curve, the same intercept of the ordinate at zero current was used as in Fig. 3, and the curve extrapolated in a straight line through these two points. Note, however, that in such a method of extrapolation, the higher the value given the intercept at zero current, the lower the value of ultimate rise at currents greater than full load and, conversely, the higher the value of ultimate rise at currents less than full load. It is important, therefore, to know the correct value for the intercept, but it is safer to assume a low value rather

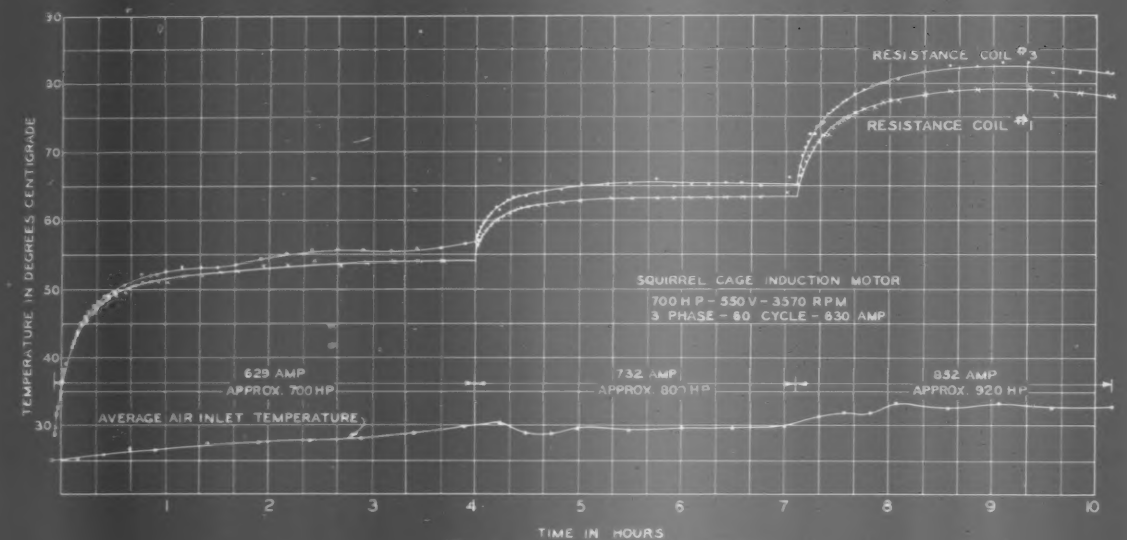


Fig. 7—Time-Temperature Curves

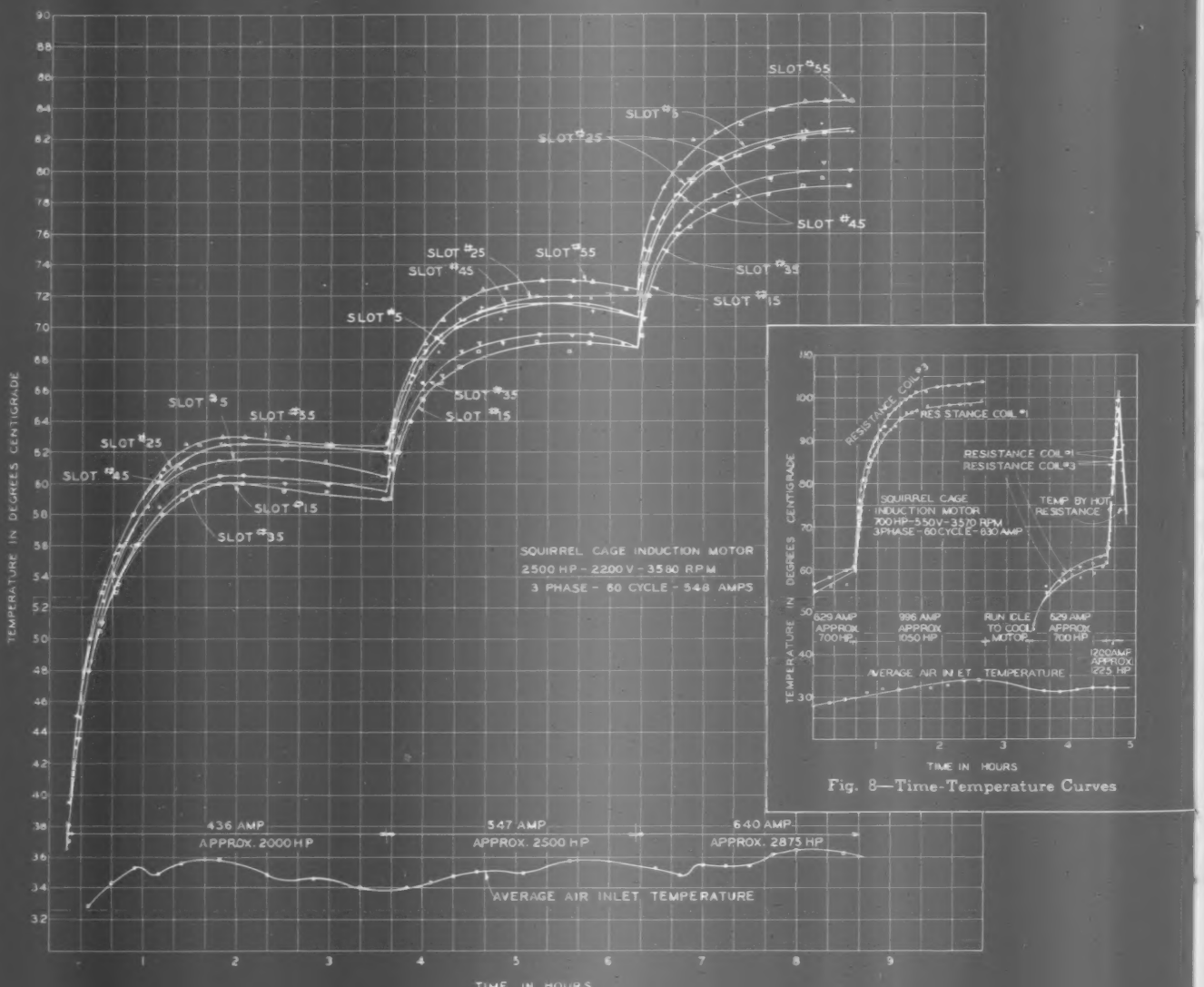


Fig. 9—Time-Temperature Curves

Fig. 8—Time-Temperature Curves

than too high a value insofar as any leeway or factor of safety is concerned when calculating temperatures for overload conditions.

Figures 7, 8, and 9 show actual time-temperature curves taken on 3600 rpm induction motors under various conditions of starting from ambient temperature and superimposing one load on another. The curves are self-explanatory. A certain amount of recirculation of ventilating air, which is difficult to prevent entirely under commercial testing conditions, will account for the variation in the air inlet temperature; the variation is not sufficient to affect the results appreciably although a constant air inlet temperature is preferable when time-temperature tests are made.

Actual double exponential curve

When the actual test curves are replotted on semi-logarithmic paper, the results are shown in Figs. 10-14. As might be expected, the rate of rise at first is comparatively rapid, as the copper loss is absorbed by the copper, which, as previously indicated, has a shorter time constant; the curves flatten out as the machine comes up to temperature and as the effect of the iron, with its much longer time constant, tends to become the predominant factor.

As intimated previously, these curves can all be fitted very closely by means of double exponential equations of the form of equation (8). For example, the upper curve for Slot No. 55, shown in Fig. 10, can be expressed as follows:

$$(9) \qquad \frac{y-y_o}{Y-y_o}=0.63\,(1-\varepsilon^{-t/8.2})+0.37\,(1-\varepsilon^{-t/30})$$

An examination of Fig. 10 shows that the curve in its lower range, as plotted on inverted semi-logarithmic paper, can be closely approximated by a straight line (indicated by the extended dotted line), and that the same straight line can be made to represent the variation for both temperature detectors that were used in the test. This straight line has a time constant of 12 minutes. Because of the peculiar nature of the logarithmic scale mentioned previously, the straight line appears to follow the test points for only a short distance, but examination shows that it follows the points very closely up to about 60% of the total rise. Furthermore, the region where it departs from the test points is that in which the scale is exaggerated so that the deviation is less than appears from this curve.

To give a better picture of the amount of approximation involved, Fig. 15 has been plotted on regular graph paper. It shows that the single and double exponential curves coincide at the lower temperatures and that the double exponential curve (and the actual test curve) flatten out more rapidly as the ultimate temperature rise is approached.

The lower region is the most important; if the machine is designed to operate safely at a temperature corresponding to a value anywhere near the ultimate rise for a given load, it would often be considered better practice to design it to carry that load continuously. The application of short-time ratings is most common when the safe temperature is well below the ultimate temperature. Since the double exponential is somewhat cumbersome to handle, it is apparent that for those cases where "t" does not exceed approximately 10 minutes, the single exponential curve, equation (1), can be used with the knowledge that it will give about the same accuracy as the double exponential curve. For those cases where "t" extends beyond 10 minutes, the double exponential curve should be used where accuracy is required. For fairly close approximations, the single exponential curve can be used because the results obtained will always be on the safe side, the single exponential curve indicating higher temperature rises than the double exponential curve in those cases where t=10 minutes or more. This is clearly shown by the curves in Fig. 15.

Actual single exponential curve

Of special interest is the fact that all of the curves for each of the motors for which tests are shown in Figs. 10-14 can be approximated as described above

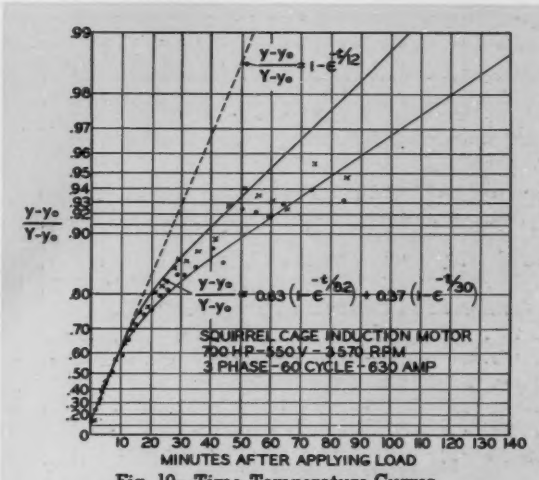


Fig. 10—Time-Temperature Curves
700 Hp Run Starting Cold

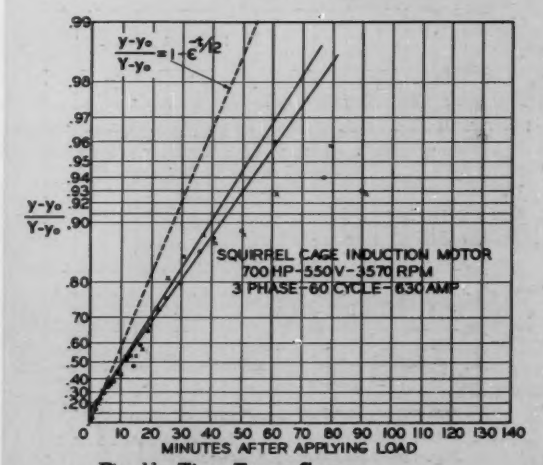


Fig. 11—Time-Temp. Curves
800 Hp Superimposed upon 700 Hp

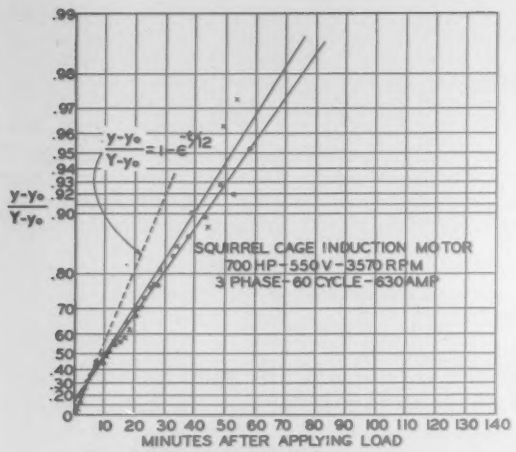

y-y₀ / Y-y₀
y-y₀ / Y-y₀ = 1-ε^(-t/12)
SQUIRREL CAGE INDUCTION MOTOR
700 HP-550 V-3570 RPM
3 PHASE-60 CYCLE-630 AMP
MINUTES AFTER APPLYING LOAD

Fig. 12—Time-Temp. Curves
920 Hp Superimposed upon 800 Hp

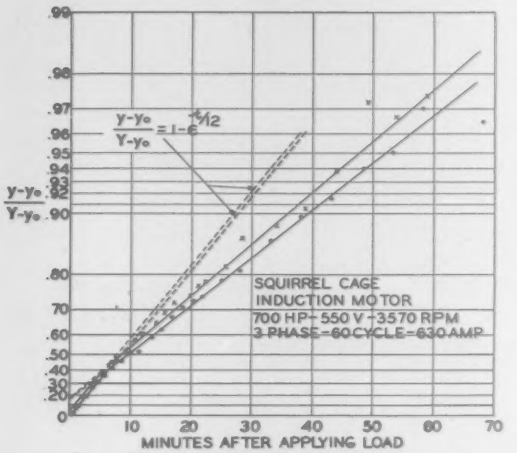


Fig. 13—Time-Temp. Curves
1050 Hp Superimposed upon 700 Hp

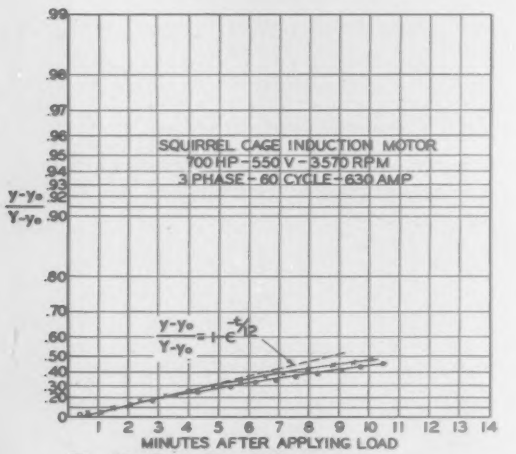

y-y₀ / Y-y₀
SQUIRREL CAGE INDUCTION MOTOR
700 HP-550 V-3570 RPM
3 PHASE-60 CYCLE-630 AMP
y-y₀ / Y-y₀ = 1-ε^(-t/12)
MINUTES AFTER APPLYING LOAD

Fig. 14—Time-Temp. Curves
1225 Hp Superimposed upon 700 Hp

by single exponentials with the same time constant regardless of the magnitude of the load, whether the load is applied to the machine at ambient temperature or superimposed upon a previous load. The time constant obtained from these curves is 12 minutes for the 700 hp motor and 15 minutes for the 2500 hp motor. (Straight lines with their time constants are dotted in on all the curves.) This is in line with theory and past experience, which indicate that the thermal time constant of electrical apparatus does not vary greatly over a wide range of loads and sizes.

The actual single exponential equation can then be approximated by

$$(10) \qquad \frac{y-y_o}{Y-y_o}=1-\varepsilon^{-t/\tau}$$

where τ varies from 10 to 25 minutes or more, depending on the size and speed of the machines involved. It is recommended, whenever possible, that τ, the thermal time constant for the single exponential method, be derived from an actual time-temperature test at any given load on the actual motor under consideration or one similar to it. It is recognized that as the size of the machine goes up, τ tends to increase in time to some extent.

This equation can be put in the following form:

$$(11) \quad t=\tau \log_\epsilon \left(\frac{y-y_o}{Y-y}\right)$$

$$\text{where } \log_\epsilon \left(\frac{Y-y_o}{Y-y}\right)=2.30 \log_{10} \left(\frac{Y-y_o}{Y-y}\right)$$

Method of application—Example No. 1

Assume that a 1000 hp motor has already been given a time-temperature heat run at full load and that at this load the ultimate temperature rise is already known to be 42 C by embedded temperature detector. The problem is to ascertain for how long a time the motor can be run at 35% overload in current, starting with the motor "cold" at room or ambient temperature, without exceeding 55 C rise by embedded detector. Assume that the ambient temperature is 30 C.

First, plot the time-temperature points from the heat run that was made. Since this is an exponential curve, the binary time, at 50% of the total rise (see Fig. 1), is

$$\tau_b=0.693\ \tau \text{ minutes}$$

and therefore τ, which is the time in minutes at the intersection of the rate of rise and the ultimate temperature, is

$$\tau=\frac{\tau_b}{0.693} \text{ minutes}$$

If $\tau_b=10$ minutes, then $\tau=\frac{10}{0.693}=14.4$ minutes.

A more accurate method of determining the time constant from the test would be to plot the points in a manner similar to Figs. 10-14.

Second, draw a curve, Fig. 16, similar to Fig. 5, showing the temperature rise plotted as a function of stator current. If test runs at two loads are not available, one point may be plotted and a zero intercept assumed, as explained previously. Obtain

the ultimate temperature rise in deg C from an abscissa value which is

$$\left(\frac{1.35}{1.00}\right)^2 \times \frac{234.5+55+30}{234.5+75}=1.88$$

This ultimate temperature rise then is 75 C (from Fig. 16).

Third, the time, t, in minutes, that the motor can carry this 35% overload in current starting at ambient temperature without exceeding 55 C rise by embedded detector in an ambient temperature of 30 C, is obtained from equation (11), and

$y = 55$ C
$y_o = 0$ C
$Y = 75$ C

$$t = 14.4 \log_\epsilon \left(\frac{75-0}{75-55}\right) = 19 \text{ minutes.}$$

If the motor is brought up to speed from standstill immediately preceding this loading, the initial temperature rise caused by the starting operation should be taken into account, thereby decreasing the permissible loading time. If, on the other hand, it is running idle before the load is applied, there is still an initial rise because of the no-load losses and the magnetizing current, as will be seen in Example No. 3.

Example No. 2

Assume the same conditions as in Example No. 1, except that the problem now presented is to ascertain for how long a time the motor can be run on an overload of 35% in current superimposed on full load, with the motor already at 42 C rise, without exceeding 55 C rise by embedded detector.

First, $\tau = 14.4$ minutes, as in Example No. 1.

Second, the ultimate temperature rise is 75 C, as in Example No. 1.

Third, the time, t, that the motor can carry this superimposed overload of 35% in current without exceeding 55 C rise is

$$t = 14.4 \log_\epsilon \left(\frac{75-42}{75-55}\right) = 7.2 \text{ minutes}$$

where $y = 55$ C
$y_o = 42$ C
$Y = 75$ C

Example No. 3

Assume the same condition as in Example No. 1, except the problem now presented is to ascertain for how long a time the motor can be run at 35% overload in current after it has been running idle without load for a considerable amount of time without exceeding 55 C rise by embedded detector. Assume, for this case only, that the idle running load is practically negligible and that under these conditions the current taken by the motor is the magnetizing current only.

First, $\tau = 14.4$ minutes, as in Example No. 1.

Second, the ultimate temperature rise is 75 C, as in Example No. 1.

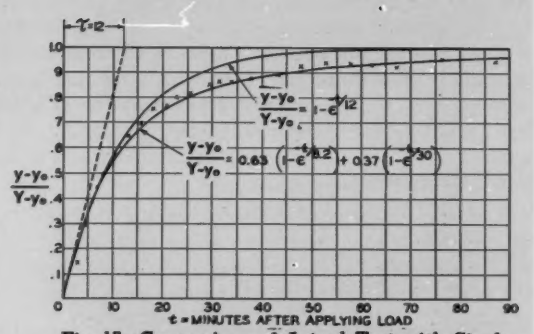


Fig. 15—Comparison of Actual Test with Single and Double Exponential Curves

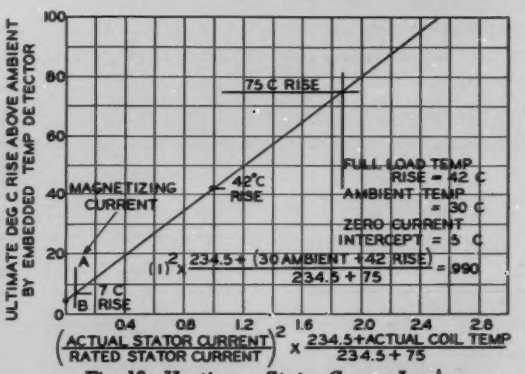

ULTIMATE DEG C RISE ABOVE AMBIENT BY EMBEDDED TEMP DETECTOR
75 C RISE
MAGNETIZING CURRENT
42°C RISE
FULL LOAD TEMP RISE = 42 C
AMBIENT TEMP = 30 C
ZERO CURRENT INTERCEPT = 5 C
A
B
7 C RISE
(ACTUAL STATOR CURRENT / RATED STATOR CURRENT)² X (234.5+ACTUAL COIL TEMP) / 234.5+75

Fig. 16—Heating vs Stator Copper Loss

Third, the time, t, that the motor can carry this 35% overload in current under the conditions named, noting that y_o is now 7 C, is

$$t = 14.4 \log_\epsilon \left(\frac{75-7}{75-55}\right) = 17.6 \text{ minutes}$$

where $y = 55$ C
$y_o = 7$ C
$Y = 75$ C

Limitations

In order that the data presented herewith may be of value in the prediction of temperatures or temperature rises, certain limiting values must be placed on the ultimate temperatures so that time, type of insulation, and temperatures may all be correlated.

For various loadings, Table I shows the observable temperature and observable temperature rises based on 40 C ambient temperature. These data are given in the A. I. E. E. Standard No. 1, June, 1940.[1]

It is reasonable that any loading that gives an observable temperature rise of 50 C for Class "A" material by the thermometer method cannot be subjected to any greater short time rating in a 40 C ambient without causing accelerated deterioration of coil insulation.[43] For those machines which are not "maximum" rated, the observable temperature rises shown by Table II are frequently used, especially when applied to synchronous motor, generator, and induction motor ratings.[2]

Using such values, therefore, sets a limit so that any further loading and time of superimposed load is set by the safe limiting temperatures with respect to the class of insulation, as shown by the tables.

If the insulation of a machine restricts its heating on normal load to 40 C rise by thermometer based on 40 C ambient, the time of the overload should be restricted in this particular case to a maximum observable temperature rise by thermometer of 50 C when using Table I, and a maximum observable ultimate temperature by thermometer of 90 C. These would be the limitations of a machine having Class "A" insulation.

The examples given in this paper use a 30 C ambient in order to stress the point that it is not well

Method	Class "A" Material		Class "B" Material	
	Safe Limiting Temperature A. I. E. E.	Rise A. I. E. E.	Safe Limiting Temperature A. I. E. E.	Rise A. I. E. E.
Thermometer	90 C	50 C	110 C	70 C
Resistance	100 C	60 C	120 C	80 C
Embedded Detector	100 C	60 C	120 C	80 C

Table I — Limiting Observable Temperatures and Temperature Rises

Method	Class "A" Material		Class "B" Material	
	Safe Limiting Temperature A. I. E. E.	Usual Rise Specified	Safe Limiting Temperature A. I. E. E.	Usual Rise Specified
Thermometer	90 C	40 C	110 C	50 C
Resistance	100 C	50 C	120 C	60 C
Embedded Detector	100 C	50 C	120 C	60 C

Table II — Usual Temperature Rises Specified for A. I. E. E. Safe Limiting Temperature

to form a habit of always assuming an ambient of 40 C. Careful consideration must be given this question.[55] When the ambient fluctuates widely during a given period of time, then the loading of the motor should either be limited to a value that can safely be carried at the maximum ambient temperature or varied as the ambient temperature changes from time to time.

Conclusion

It is self evident that in the intelligent application of any of the above data, especially as to overload conditions, the more that is known of the actual temperatures in any particular machine, the closer the overload capabilities can be predicted. For those cases in which no actual test data are available, certain constants must be assumed from known values on similar machines. The three cases worked out in this paper were picked as examples of different types of short-time overload.

It is very seldom that a 40 C rise rated machine actually rises 40 C on test. It may rise only 30 C or 35 C, for example, or the overload may be superimposed on the normal load before the temperatures have become constant, or the ambient may be other than 40 C. For these reasons the time-temperature curves have been made with their vertical ordinates in percent temperature rise rather than actual degrees temperature rise. This makes an arrangement which is flexible and easily adjusted to the many different conditions that exist.

For reasons already given, the time-temperature curves and other temperature curves given in the paper are all based on the use of embedded temperature detectors which have the same limitations with respect to time and type of insulation as the resistance method. The same precepts can also be applied to the thermometer method by merely redrawing the curves and abiding by the different safe limiting restrictions as set forth in Table I.

In the case of synchronous machines operating at constant excitation, the same methods apply for determining the overload capacity of the stator. If the excitation is varied to maintain constant power factor or constant voltage, however, the field may be the limiting factor. The field can be considered independently according to the general principles set forth here.

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WHAT'S THE ANSWER?

Question — Can the current drawn by a synchronous motor during starting prior to pull-in be reduced by reducing the mechanical load on the motor?

Answer — No. The current drawn by a synchronous motor during that part of the starting period preceding the application of direct current excitation depends only upon the speed of the motor (assuming constant applied voltage and frequency). Reducing the load will cause the motor to accelerate more rapidly, but the curve of current plotted against speed remains unchanged.

Question — Our 5000 kw, 80 percent power factor, 3600 rpm turbine-generator unit built in 1915 is no longer used since the boilers in this station have been out of service for some time. During certain hours of the day, the load power factor in the vicinity of this old plant is such that it would be desirable to operate the 5000 kw generator as a synchronous condenser. Can this be done?

Answer — The use of turbine-generators as synchronous condensers is a matter of common practice although frequently not justifiable economically. For equal field heating the above machine will carry approximately 5000 kva at 0 percent power factor as a synchronous condenser, but the corresponding losses will be about twice those for a modern 5000 kva synchronous condenser.

For continuous duty a new synchronous condenser, by virtue of its lower losses, would pay for itself and show a return on its investment over a period of time. For occasional service, on the other hand, operation of the old unit may be feasible.

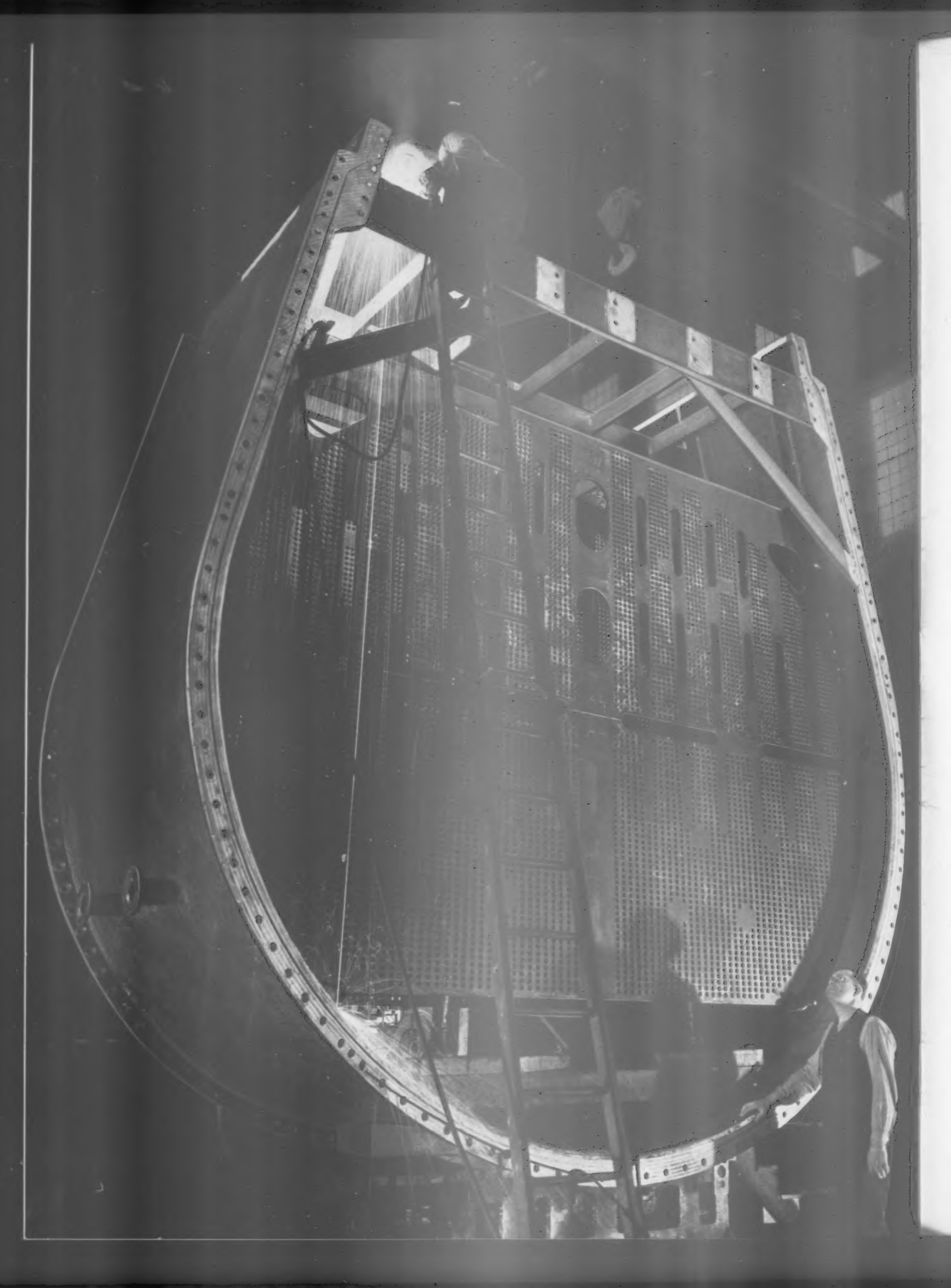
Normally lubrication is supplied by the turbine oil pump. If the turbine is disconnected, a separate lubricating source is required. Moreover, some external means of starting must be provided, and often an additional high pressure lubricating system to reduce the starting torque.

On lower speed machines, if a d-c source of supply is available, the direct-connected exciters are often used for starting, with the aid of the special high pressure lubrication. Direct-connected exciters on high speed machines are seldom large enough to carry the core loss as well as the high windage loss while synchronizing.

If a-c power is available, a separate slip ring type of belt-connected starting motor can sometimes be used to bring the generator up to the correct speed for synchronizing.

A synchronous condenser can in some cases also be brought up to speed simultaneously and in synchronism with a steam-turbine-driven generator. Full field is applied on the generator and a lighter field on the synchronous condenser.

"What's the Answer?" is conducted for the benefit of readers of ELECTRICAL REVIEW who have questions on central station, industrial or power plant equipment. Send all questions to the Editors of ELECTRICAL REVIEW.



ZERO SEQUENCE IMPEDANCE

W. C. Sealey, **Engineer-in-Charge**

TRANSFORMER DESIGN • ALLIS-CHALMERS MANUFACTURING COMPANY

Presenting a method of calculating impedance of transformer windings to zero sequence currents... a necessary step in symmetrical component calculations where an unbalanced polyphase circuit must be reduced to equivalent balanced circuits.

For obtaining current and voltage relations in three-phase circuits, the method of symmetrical components divides the currents into three balanced components as follows: a positive phase sequence component, a negative phase sequence component, and a zero phase sequence component.

For static transformers the impedance to the positive and the impedance to the negative sequence components of current are the same and are found in the well known conventional equivalent circuits of transformers.

The impedance to the zero-sequence currents may be quite different from the positive sequence impedance, or it may be the same, depending on the transformer construction and connections.

The zero-sequence impedance of a three-phase transformer or three-phase transformer bank is the impedance to equal in-phase currents in each line or each winding. (The zero-sequence currents in each of the three conductors are not only numerically equal but are also in phase with each other.)

Therefore, if zero-sequence currents flow in a three-phase line, they must return through a neutral connection. If there is no neutral connection (as in the case of delta-delta transformers), no zero-sequence line current can flow, and the zero-sequence impedance to line currents is equal to infinity. Of course, zero-sequence currents can flow in the delta-connected windings (circulating around the delta) but not in the line conductors.

Transformers with no neutral

When no winding has a neutral brought out, the impedance to zero-sequence line currents is equal to infinity. Examples of such transformer connections are shown in Fig. 1.

Transformers with single neutral

Typical transformer connections where only one winding has a neutral brought out are shown in Fig. 2.

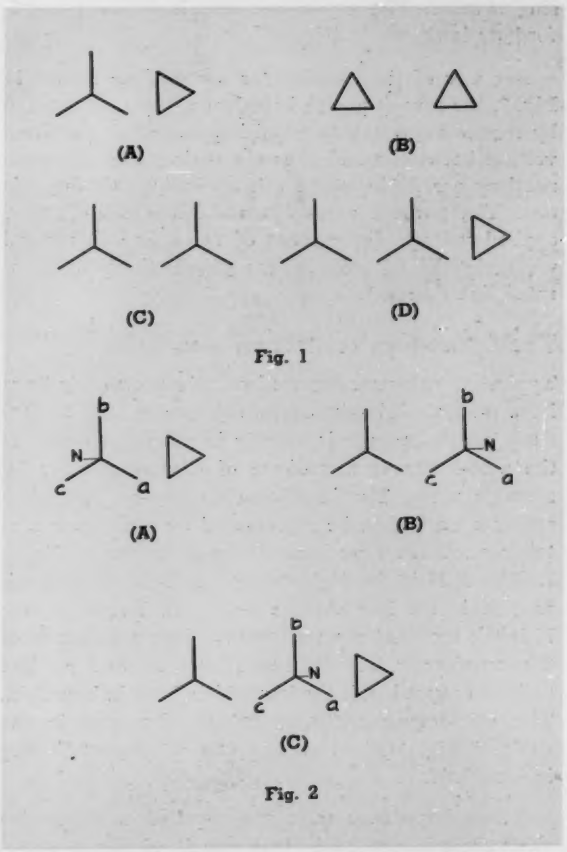


Fig. 1

Fig. 2

AT LEFT: Assembling one of the three sections required to make up the complete shell of a 35,000 sq ft, two-pass surface condenser.

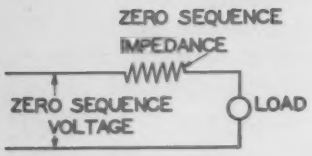


Fig. 3

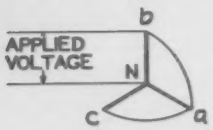


Fig. 4

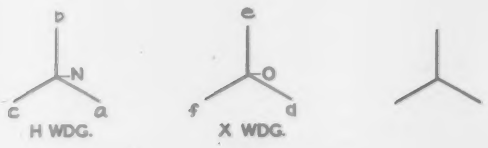


Fig. 5

For all such transformers the zero-sequence impedance of the windings without neutral to zero-sequence line currents is equal to infinity, and the zero-sequence impedance of the transformer can be expressed by a single value. The equivalent circuit of such transformers is shown in Fig. 3.

For any of the transformer connections shown in Fig. 2, the zero-sequence impedance may be measured by connecting a to b to c and impressing single phase voltage between a and N as shown in Fig. 4. No connections are made to the other windings during this test. The percent zero-sequence impedance = 100 × applied voltage (in percent of rated line to neutral voltage) ÷ the current in one phase (in percent of rated line current).

Transformers with two neutrals

Typical transformer connections where two windings have neutrals brought out are shown in Fig. 5. For such transformers it is usually impossible to express the zero-sequence impedance of the transformer by a single value. The impedance to zero-sequence line currents must then be represented by a network containing at least three impedances, as shown in Fig. 6. In Fig. 6, H is the high voltage or H winding terminal; X is the low voltage or X winding terminal; K is the terminal representing the internal circuits of the transformer. The difference between the input kva and the output kva is the kva which flows in branch K. The zero-sequence current which circulates in the delta of Fig. 5(B) is an example of current flowing in branch K.

Three impedance tests are required to determine the values in the equivalent circuit of Fig. 6 corresponding to any of the transformer connections of Fig. 5.

1. To determine the impedance $Z_1 = Z_H + Z_K$. Connect a to b to c and apply single phase voltage between a and N. The percent impedance $Z_1 = Z_H + Z_K$ = 100 × applied voltage (in percent of rated line to neutral voltage) ÷ phase current (in percent of rated line current).

2. To determine the impedance $Z_2 = Z_X + Z_K$. Connect d to e to f and apply single phase voltage between d and O. The percent impedance $Z_2 = Z_X + Z_K$ = 100 × applied voltage (in percent of rated line to neutral voltage) ÷ phase current (in percent of rated line current).

3. To determine the impedance of Z_3. If d is connected to e to f to O and if a is connected to b to c and single phase voltage is applied between a and N, the impedance $Z_3 = Z_H + \dfrac{1}{\dfrac{1}{Z_X} + \dfrac{1}{Z_K}}$ since branches X and K are in parallel and will divide the H kva between them.

These three equations can be solved simultaneously to determine Z_H, Z_X, and Z_K, giving the following results:

$$Z_K = (Z_1 - Z_3)\, Z_2$$
$$Z_H = Z_1 - Z_K = Z_1 - (Z_1 - Z_3)\, Z_2$$
$$Z_X = Z_2 - Z_K = Z_2 - (Z_1 - Z_3)\, Z_2$$

If the power is applied on the H winding and the zero-sequence load is on the X winding, the equivalent circuit is completed as in Fig. 8(A). If there is no zero-sequence current in the X winding, the

equivalent circuit is completed as in Fig. 8(A) which reduces to a single impedance as in Fig. 8(B). If the power is applied on the X winding and the zero-sequence load is on the H winding, the equivalent circuit is completed as in Fig. 8(C).

Auto transformers

The equivalent circuits for auto transformers are the same as for transformers with separate windings having the same connections except for the case where the supply neutral is grounded but where no auto transformer neutral is brought out.

Figure 7 shows the circuit of an auto transformer with the auto neutral brought out. This connection in effect has the neutrals brought out on two windings, since the two windings have a common neutral, and consequently belongs to the same group as the transformers of Fig. 5. Its equivalent circuit is shown in Fig. 6, which can be completed as shown in Fig. 8. The tests for determining the constants for the equivalent circuit are exactly the same tests as those described under "Transformers with Two Neutrals." If the delta-connected winding were omitted from Fig. 7, the tests and the equivalent circuits would be the same, but the numerical values of the circuit constants would be different.

Special auto transformer case

One special case which may occur with auto transformers that does not occur with transformers with separate windings is the case where the supply neutral is grounded and the zero-sequence load occurs on the side of the transformer away from the source, as in Fig. 9, and flows from the source to the load. For this case a single impedance test with a connected to b to c and with d connected to e to f, with single phase voltage applied from a to d will determine the value of the impedance in the equivalent circuit Fig. 3.

The percent zero-sequence impedance in percent of the high voltage kva is equal to 100 × the applied voltage (in percent of rated high voltage to neutral) ÷ the current (in percent of full load high voltage current).

The kva base for the low voltage side is equal to the kva for the high voltage side × the ratio of transformation (ratio of low voltage to high voltage at no load).

This difference in kva base must be considered when adding the other impedances in the circuit. The impedances on the high voltage side must be on the high voltage kva base, and the impedances on the low voltage side on the low voltage kva base. Likewise the percent currents on the high voltage side are on the high voltage kva base, and those on the low voltage side on the low voltage kva base.

Example: An auto transformer connected as in Fig. 9. High voltage 13,800 volts; low voltage 6900 volts.

All the zero-sequence impedances given are on a 10,000 kva 3-phase base. The zero-sequence impedance of the transformer measured from the high voltage side, as described, is 6 percent. The zero-sequence load impedance on the low voltage side is 10 percent. The zero-sequence impedance of the generator is 12 percent.

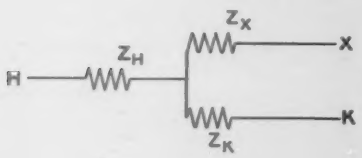
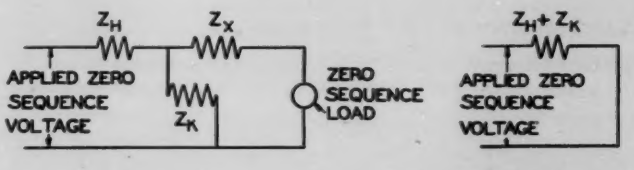


Fig. 6



(A) (B)

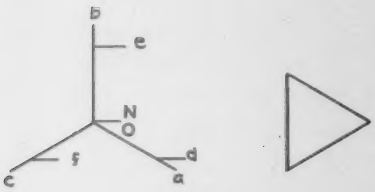
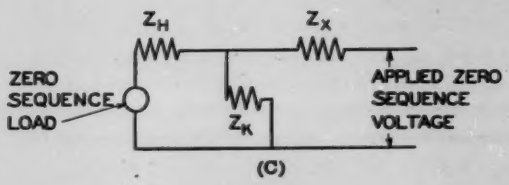


Fig. 7



(C)

Fig. 8

Required: The zero-sequence impedance of the circuit.

Solution: The total zero-sequence impedance in the circuit is equal to $12+6+\frac{6900}{13800}\times 10 = 23$ percent on a 10,000 kva high voltage kva base. The zero-sequence kva flowing in the X lines is equal to $\frac{6900}{13800}\times$ the zero-sequence kva flowing in the H lines.

Typical values of zero-sequence impedance

For any transformer with an iron core, because of the saturation of the iron, the zero-sequence impedance will vary with the current being carried. For commercial transformers, the variation is negligible when one of the windings is delta-connected but may be considerable when there is no delta-connected winding.

For single-phase transformers connected delta-star with the neutral out, the zero-sequence impedance is the same as the positive sequence impedance, which is generally between three and 15 percent.

For three-phase transformers connected delta-star with the neutral out, the zero-sequence impedance is slightly lower than the positive or negative sequence impedance, the difference being greater for the core type than for the shell type.

For three-phase transformers connected as in Fig. 2(B) (Y-connected with the neutral out), without a delta winding and with no neutral connection to another neutral, the zero-sequence impedance varies with the current. Its value for core type transformer is generally between 25 percent and 75 percent.

For shell type transformers such a connection is seldom used, but if used, the zero-sequence impedance varies with the current over an extremely wide range and has a minimum value of impedance considerably more than 100 percent.

Approximations

In general, the equivalent circuit of Fig. 6 should be used for all transformers which have two neutrals brought out. However, in some cases, the simpler circuit of Fig. 3 can be used with only slight error.

For YY-connected transformers without delta windings but with two neutrals, at least one of which is connected to an established neutral, and where the bank is composed of three single-phase transformers of any type or one three-phase shell type transformer, the value of Z_K is very large compared to the other impedances in the circuit. Consequently, the equivalent circuit of Fig. 3 can be used for such a bank without appreciable error.

For YY-connected auto transformers, with close to a 1-to-1 ratio of transformation when the neutral is connected to an established neutral, the value of Z_K is large compared to the other impedances in the circuit. Consequently, the equivalent circuit of Fig. 3 can be used for such transformers without appreciable error. A common example of such an auto transformer is a standard step type regulator for plus and minus 10 percent regulation when its neutral is connected to a system neutral.

In each of the above cases, the impedance to be used in Fig. 3 is the impedance Z_3 obtained as described in test No. 3 for transformers with two neutrals out.

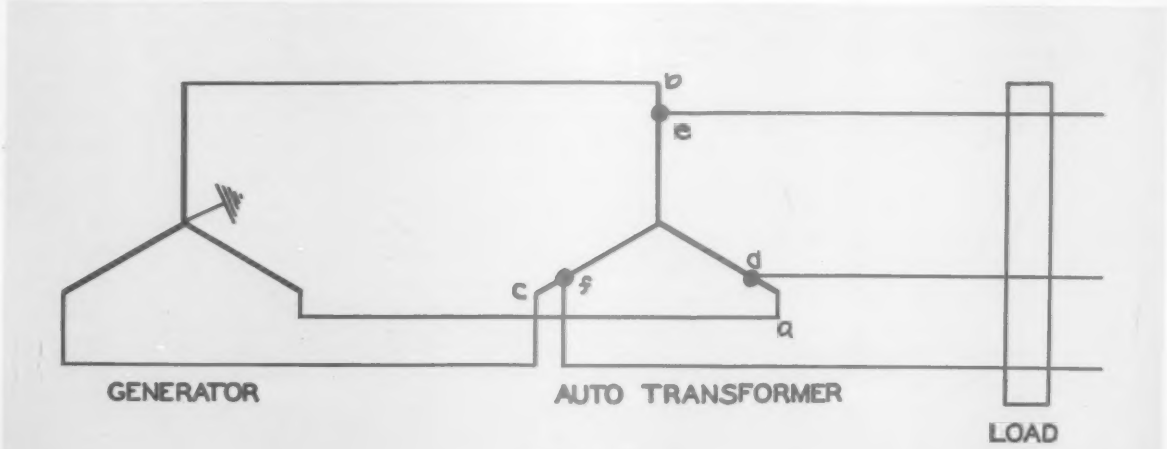


Fig. 9

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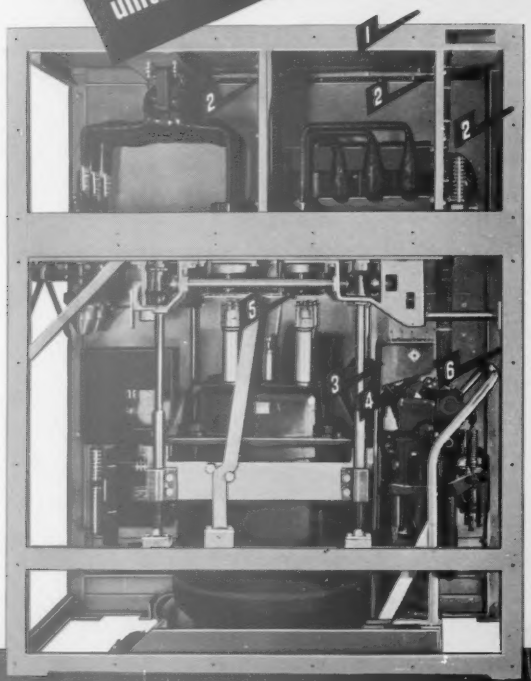

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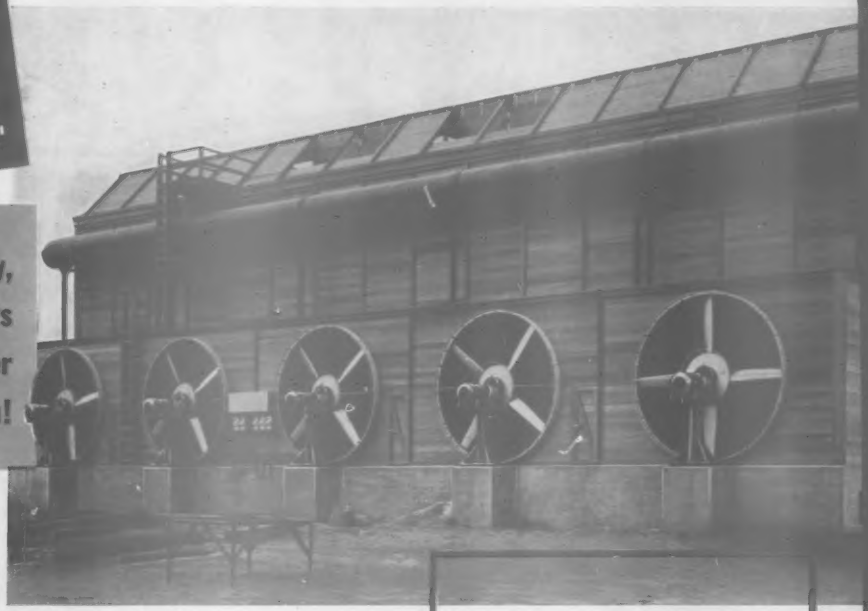

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But when it has to be done outdoors in all kinds of Texas Panhandle weather — in heat . . . in rain and dust storms . . . then you've got a situation that calls for motors that are *better* than ordinary.

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That's why they selected these same motors . . . why today they can snap their fingers at all the hazards of outdoor motor service in the Texas Panhandle. And best of all — they know they'll continue to get low-cost, dependable service for many years to come.

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